Weeds

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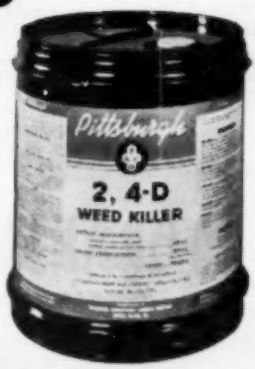

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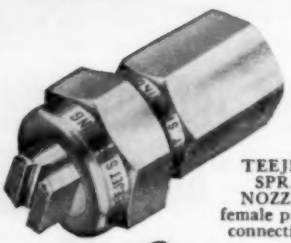

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Weeds

JOURNAL OF THE ASSOCIATION OF REGIONAL WEED CONTROL CONFERENCES.

VOLUME III APRIL 1954 NUMBER 2

Killing Native Barberry With Hormone-type Herbicides

L. W. MELANDER, E. A. LUNGREN, and W. M. WATSON[1]

VARIOUS species of barberry serve as alternate hosts of the destructive stem rust disease of wheat, oats, barley and rye. Eradication of susceptible barberry plants is one of the principal control measures.

Two rust-susceptible species of barberry—*Berberis fendleri* Gray and *B. canadensis* Mill.—are indigenous to some of the states where eradication measures are being undertaken, primarily in Colorado, Virginia, and West Virginia. They are woody plants that grow in patches and reproduce to some extent by seed but principally by rhizomes. The large areas of infestation present a difficult eradication problem. Since 1934, when these native species were first scheduled for eradication, many chemicals have been tested in an effort to find effective inexpensive herbicides that could be used on a year-round basis and that would not endanger animals or harm valuable associated shrubs and trees.

PREVIOUS RELATED WORK

In 1921 W. S. Regan,[2] of the Bureau of Plant Industry, U. S. Department of Agriculture, observed that crushed rock salt killed the European barberry *(B. vulgaris L.)*, and Baringer (1) found that kerosene would also kill this species. In the same year Thompson and Robbins (11) established comprehensive experiments to find a herbicide for eradicating this barberry. They tested 37 chemicals, classified as inorganic salts, acids and acid formers, gas formers, oils, and other organic substances, both as foliage sprays and crown-and-soil drenches. Sodium chloride, kerosene, and sodium arsenite were found to be the most toxic. Sodium chloride proved to be the most satisfactory and was adopted in 1923 for general use on the barberry eradication project. The poisonous nature of sodium arsenite made it undesirable for field use. In 1931 and 1932[3] ethylene oxide and

[1]Plant Pest Control Branch, Agricultural Research Service, U. S. Department of Agriculture, Minneapolis, Minn. The authors acknowledge the cooperation and assistance given by field and other project personnel. They express their thanks to the various members of the herbicide industry for making available numerous samples.

[2]Unpublished.

[3]Annual reports of barberry eradication in Minnesota. (Unpublished.)

ammonium thiocyanate were found to be effective for killing *B. vulgaris* under certain conditions but unsatisfactory for general use. In 1928 Melander[3] made tests with acetic acid but found it to be ineffective.

Beginning in 1934, tests with a few chemicals that held the most promise were made on *B. fendleri* by E. A. Lungren, H. Offord, and W. M. Watson in Colorado and on *B. canadensis* by T. Van Zanden and G. E. Matheny and coworkers in the Virginias.[2] These chemicals included sodium chlorate, sodium chlorate plus borax, Atlacide (a proprietary compound containing sodium chlorate plus a fire-inhibiting substance), diesel oil, ammonium thiocyanate, sodium chloride (brine and dry salt), sodium hydroxide, and sulfuric acid sludge. Atlacide was found most generally satisfactory and was adopted for field use on *B. fendleri* in Colorado. The dry salt and brine of sodium chloride were selected for destroying *B. canadensis*, but this salt was subsequently replaced by Atlacide. Eradication with these chemicals was slow and expensive, the cost ranging from $1.25 for common salt to $1.70 per square rod for Atlacide.

During the period 1942–45 ammonium sulfamate as a dry salt and in solution was tried on all three species—*B. vulgaris, B. fendleri,* and *B. canadensis* (12). This chemical was generally effective on native barberry, although the amount required to kill made the cost prohibitive. However, European barberry *(B. vulgaris)* later was found to be killed with small amounts of the dry salt of this chemical applied to the surfaces of cut canes (2).

The discovery of the herbicidal effect of hormone-type chemicals (9) in the early 1940's gave new impetus to the chemical eradication of barberry. In 1946 experiments were initiated in the Virginias and Colorado to check the efficacy of 2,4-D and other hormone-type chemicals on the native species of barberry. These experiments are summarized in this paper. Partial results were reported at the North Central Weed Control conferences in 1947, 1948, and 1950 (3, 4, 5, 6, 7, and 8).

MATERIALS AND METHODS

Since in 1946 no information was available as to the effect of the hormone-type herbicides on native barberry, experimental plots were established to test different combinations and concentrations of those then available—i.e., sodium, ammonium, and triethanolamine salts, and various esters of 2,4-D (2,4-dichlorophenoxyacetic acid). Later, salts and esters of 2,4,5-T (2,4,5-trichlorophenoxyacetic acid) and 4-chloro-o-toloxyacetic acid were included. In all salt solutions except those containing a detergent, a commercial sticker-spreader was used. In an attempt to facilitate penetration, acetic acid was added to certain mixtures. In these first tests the chemicals were applied as foliage sprays with water as the diluent.

In the fall of 1947 experiments were begun to test the hormone-type chemicals on native barberry in the dormant stage. Patches of barberry bushes rather than uniform sized plots were treated. The spray was applied as an over-all coverage with special emphasis on ground line and surrounding soil. Approximately 100 gallons per

acre were applied. Oil solutions (distillate) of various esters of 2,4-D and 2,4,5-T, separately and in combination, in concentrations of 3.5 to 14 pounds acid equivalent per hundred gallons (ahg), were applied in sprays at monthly intervals during the dormant season.

As data were obtained on both the foliage and dormant stages, enlarged field tests were run with the mixtures that had given the best results in the plots.

The chemicals were applied to the bushes by means of knapsack sprayers for small isolated patches and power sprayers for the large infestations. A special power sprayer using compressed air as a propelling force was designed and constructed. It has proved satisfactory and has increased the speed and efficiency of field treatments.

TESTS WITH FOLIAGE SPRAYS

Foliage sprays were the first to be tried with 500 to 2,000 ppm (0.4 to 1.6 ahg) of chemicals, using water as a diluent (table 1). One-

Table 1. Effectiveness of hormone-type herbicides (2,000 ppm) applied as foliage sprays to native barberry bushes on quarter square-rod plots in Colorado and the Virginias, 1946–49.

Herbicide	*B. canadensis**				*B. fendleri**			
	Number of years tested	Season treated			Number of years tested	Season treated		
		Early	Mid	Late		Early	Mid	Late
2,4-D—								
Acid + wetting agent	–	–	–	–	1	G	F	F
Acid + wetting agent + acetic acid	–	–	–	–	1	G	F	F
Acid + detergent	2	P	P	P	2	E	G	F
Acid + detergent + acetic acid	2	P	F	P	2	E	G	G
Sodium salt	3	I	I	P	3	F	G	F
Sodium salt + acetic acid	1	P	P	P	1	P	P	G
Ammonium salt	1	P	P	P	1	E	G	E
Monoethyl amine	1	G	G	P	1	G	G	P
Triethylamine	2	I	I	P	1	E	E	P
Triethanolamine	4	I	I	I	4	G	G	F
Triethanolamine + acetic acid	2	P	P	P	1	G	E	G
Triethanolamine + detergent	1	P	P	P	1	G	E	–
Triethanolamine + detergent + acetic acid	1	G	G	P	1	G	G	G
Methyl ester	1	E	F	G	1	G	E	F
Ethyl ester	1	G	F	P	1	E	E	P
Butyl ester	2	I	I	I	2	G	G	F
Isopropyl ester	3	I	I	I	3	G+	G+	G
Isopropyl ester + acetic acid	2	G	F	F	2	E	G	G
4-Chloro-o-toloxyacetic acid	1	G	P	G	1	G	E	P
2,4,5-T—								
Acid + wetting agent	1	P	P	P	2	G	F	F
Acid + wetting agent + acetic acid	1	P	P	P	1	G	F	F
Acid in detergent	2	F	F	F	1	G	F	F
Acid in detergent + acetic acid	2	F	F	F	1	G	G	–
Butyl ester	2	F	P	P	1	G	G	–
Butyl ester + acetic acid	2	G	F	P	1	G	G	G
Isopropyl ester	2	F	F	P	2	G	I	I
Isopropyl ester + acetic acid	2	P	P	P	2	I	I	I
Pentasol ester from mixed amyl alcohols	1	E	P	P	1	E	E	F
Pentasol ester from mixed amyl alcohols + acetic acid	1	P	G	P	1	E	E	E
Check—Sodium chlorate (6 lbs. per square rod)	4	E	E	E	4	E	E	E

*E—excellent (over 95 per cent), G—good (86–95 per cent), F—fair (70–85 per cent), P—poor (less than 70 per cent), and I—inconsistent, expressed in relative amounts of cane kill and subsequent regrowth from roots and rhizomes.

quarter square rod plots of both *B. canadensis* and *B. fendleri* comprised the test units. The spray was applied to all above-ground parts of the plants at the rate of 2 liters per plot. Approximately 100 plots of each species were treated three times during the growing season—in the early-, midseason- and late-foliage stages.

Approximately 2,400 quarter square-rod plots of the two native species were established during the period of the experiments. The results are summarized in Table 1.

Berberis fendleri

The following sprays, containing 2,4-D and 2,4,5-T in water as a diluent, were effective on *B. fendleri:*

2,4-D	*2,4,5-T*
Ammonium salt	Butyl ester
Triethanolamine salt plus —	Butyl ester plus acetic acid
Acetic acid	Pentasol ester (from mixed amyl alcohols) plus acetic acid
Nonic 218	
Nonic 218 plus acetic acid	
Isopropyl ester alone	
Isopropyl ester plus acetic acid	

In general, *B. fendleri* appeared more sensitive to salts and esters of 2,4-D than to those of 2,4,5-T. The acids of these two chemicals dissolved in the detergent Nonic 218 gave inconsistent kills, especially in the late-foliage stage.

The location of the plots in Colorado appeared to influence the effectiveness of the salts of 2,4-D on *B. fendleri.* In small canyons, where the humidity was high, the salts were equally as toxic as the esters, but under low humidity conditions the esters performed more consistently.

Early and midseason foliage applications were more effective than those applied later. Subsequent field tests showed that the isopropyl ester and the low volatile esters of 2,4-D (butoxyethanol and isopropyl butyl ether esters) proved equally effective on *B. fendleri* when used on a field basis.

Treatment of *B. fendleri* on a field basis was begun in the summer of 1948 with foliage sprays containing the isopropyl ester of 2,4-D (1.6 pounds ahg). This initial field test was successful in that all above-ground parts were killed and there was very little sprouting the first year. After 6 years there is less than 5 percent of regrowth from roots and rhizomes.

Berberis canadensis

In repeated tests it was found that the various formulations of 2,4-D or 2,4,5-T alone or in combination with each other (1.6 pounds ahg in water) did not kill *B. canadensis* consistently in the foliage stage. It was therefore necessary to try higher concentrations in other diluents as well as with different penetrants. In these tests a mixture of 2 parts of 2,4-D to 1 part of 2,4,5-T plus pentachlorophenol with an oil diluent (distillate) was most effective. A 7-pound

ahg oil solution of this combination gave the best results in the tests and it was adopted for field use on the foliage stage of *B. canadensis* in 1950 (Fig. 1). The concentration later was increased to 10.5 pounds acid equivalent in 100 gallons of oil to give more consistent results under all types of field conditions.

Some tests on *B. canadensis,* especially in the dormant stage, with esters of 2,4,5-T in oil solution produced encouraging results but have not been sufficiently consistent to justify their use on a field basis.

FIG. 1. *Berberis canadensis* killed with hormone-type chemicals in Virginia. Area of dead grass shows extent of spraying outside the barberry patch. The grass recovers within a few months.

TESTS WITH DORMANT SPRAYS

Spraying of dormant plants of *B. fendleri* was begun on a test plot basis in January 1948 in southwestern Colorado. Various forms of 2,4-D and 2,4,5-T, with and without penetrants (turpentine and pentachlorophenol) were tested. Oil was used as a diluent. These treatments were repeated in March 1948. The percentage of kill varied and appeared to be proportional to concentration used. However, in these first tests the maximum concentration of 7 pounds ahg was not completely effective.

In the fall of 1948 monthly test plot treatments were initiated with 7 pounds ahg and 10.5 pounds ahg oil solutions of 2,4-D and 2,4,5-T esters, separately or together, on both *B. canadensis* and *B. fendleri.* All these treatments gave an almost complete kill of *B. fendleri.* Tests were repeated the next dormant season (1949–50) with the same materials with and without the penetrants. This series of tests showed that a 10.5 pound ahg oil solution containing 2 parts of 2,4-D to 1 part of 2,4,5-T plus pentachlorophenol gave 95 percent kill of both *B. canadensis* and *B. fendleri.* There was no difference in

amount of top kill, which was practically complete, but the subsequent regrowth of *B. canadensis* was less where penetrants were applied, indicating better translocation to the rhizomes. Later field tests using improved application techniques resulted in almost complete eradication of both species in the dormant stage. The ester of 2,4-D alone (10.5 ahg in oil) gave a good kill with *B. fendleri* but not with *B. canadensis.* Pentachlorophenol appeared to increase the toxicity of mixtures of these herbicides (2 parts 2,4-D plus 1 part 2,4,5-T) to *B. canadensis* but not to *B. fendleri.* Neither 2,4-D nor 2,4,5-T when used alone was effective on *B. canadensis.*

Since 2,4-D esters alone in oil solutions (diesel, distillate or kerosene) were highly effective on dormant *B. fendleri,* 2,4,5-T esters and penetrants on this species were discontinued.

DISCUSSION

Foliage and dormant stage sprays with appropriate hormone type chemicals may be considered effective on native barberries. The cane kill is practically 100 per cent and there is less than 5 per cent regrowth.

In the foliage spray tests on the plots, *B. fendleri* obviously was more sensitive to hormone type herbicides than *B. canadensis,* for it was readily killed with certain formulations of 2,4-D. 2,4,5-T was effective on *B. fendleri* but gave no better results than 2,4-D. *B. canadensis,* at least in some stages during the growing season, was tolerant to all concentrations of 2,4-D alone. This species appears somewhat sensitive to 2,4,5-T, especially in the dormant stage; however, the results are not sufficiently positive to warrant using 2,4,5-T alone.

The chemicals differed in their herbicidal effect. The isopropyl ester of 2,4-D was consistently more toxic than the salts on *B. fendleri.* Treatment at different times during the growing season showed varying effects. Under conditions of high humidity, salts were fully as effective as the esters; however, certain esters, particularly the isopropyl ester, killed *B. fendleri* consistently better under conditions of both low and high humidity.

It possibly can be assumed that as plants approach dormancy penetration is more difficult and translocation may be retarded. The early season foliage spray was more effective if applied when the leaves were fully developed and new shoots were appearing. The results of the field spraying demonstrate that the ordinary definitions of the beginning of dormancy (sloughing of leaves) and the end of dormancy (breaking of buds in the spring) cannot be used as criteria for shifting from foliage to dormant sprays or from dormant to foliage sprays.

It is difficult to determine just when to discontinue foliage spraying and to start dormant spraying. Under actual field conditions the dormant spray is used when there is evidence that the plants have ceased growth and the leaves and stems have hardened off. In Colorado we tried starting a semidormant spray with 7 pounds ahg in late summer and early fall. This was ineffective, and a full dormant

concentration of at least 10.5 pounds ahg was required. Since the time of this change varies, there is a danger that spraying crews will in some years use the foliage sprays too late in the season. It is important that the dormant-stage spray be started early enough to allow a sufficient margin of safety.

The time to discontinue dormant spraying and start foliage spraying is more clear-cut. This seems to be when the leaves are fully developed and there is evidence of new shoots. When foliage-stage spraying was started too early on *B. fendleri*, poor kills resulted.

There are indications that the 2,4-D and 2,4,5-T oil solutions are sometimes absorbed through the bark and held there until growth starts in the spring. On the other hand, in some instances the tissue of the plants is killed while the plants are dormant, because the tops are dead in the spring and there is no evidence of new growth. Apparently the chemical penetrates through the bark to the cambium of the dormant stems.

The maximum distance of penetration of the chemicals into the roots and rhizomes during dormancy is a question. It is not uncommon for the roots on plants that do not leaf out to be killed to a depth of one foot. Translocated chemicals in rhizomes have been traced for more than six feet where there had been no treatment of the surrounding soil. The killing effect often appears to stop abruptly at a point that looks like a cross wall in roots and rhizomes.

Application techniques were revised as experience was gained. To obtain a good kill, the canes must be covered thoroughly, especially at the ground line. However, to kill rhizomes effectively with foliage and dormant sprays, the solution must be applied to the surrounding soil for a radius of 4 feet beyond the last shoot. When this is done, new shoots do not develop around the patch of barberry, as was common before this spraying practice was instituted (Fig. 1).

However, the concentrations and the method of application now in use cannot be considered the ultimate in efficiency and economy. New and improved formulations and techniques are sure to be found as experience is gained over a period of years.

SUMMARY

Approximately 2,400 one-quarter square rod plots were established in Colorado and in the Virginias for testing the efficacy of foliage sprays of various formulations of 2,4-D and 2,4,5-T on native species of barberry, *Berberis fendleri* and *B. canadensis*.

Results indicate that *B. fendleri* is more sensitive to 2,4-D than to 2,4,5-T and that *B. canadensis* is more tolerant to foliage sprays of both herbicides. The results with foliage sprays of these chemicals alone on *B. canadensis* were inconsistent.

Several formulations of 2,4-D and 2,4,5-T proved effective on *B. fendleri*, but the esters of 2,4-D were consistently the best. Since low volatile esters of 2,4-D are as effective as high volatile esters on *B. fendleri*, they are being used for both the foliage and dormant sprays.

For *B. fendleri* on a field operation basis, foliage sprays (1.6 pounds

ahg with water as diluent) are applied at the rate of 200 gallons to the acre. Dormant sprays (10.5 pounds ahg with oil diluent) are applied at 110 gallons per acre. For *B. canadensis* a special mixture containing 2 parts 2,4-D to 1 part 2,4,5-T plus pentachlorophenol (10.5 pounds ahg in an oil solution) applied at the rate of 110 gallons per acre is used the year around.

While detergents, sticker-spreaders and acetic acid used in some of the foliage-spray tests increased the kill of *B. fendleri*, the differences were not consistently significant enough to warrant their use on a field basis.

Thorough spraying of every stem of native barberry bushes in both foliage and dormant stages, with special emphasis on the ground line and surrounding soil, is essential to obtain maximum kill.

The tests reported here have made possible the use of hormone-type herbicides on a year-round basis for destroying native species of barberry. Eradication costs have been reduced from $1.70 per square rod when Atlacide was used to approximately 20 cents for foliage sprays with water as a diluent and 55 cents per square rod for dormant sprays with an oil diluent. Because of the ease of application, progress has been increased by about 400 per cent.

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Influence of 2,4-D on Enzyme Systems*

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Most workers with herbicides agree that the effects brought about by many of these substances must be the results of altered enzymatic action within the plant. The actual mechanism is still a matter of conjecture in spite of some excellent research and well founded theorizing. A brief examination of enzymes and enzyme action in the light of results obtained with 2,4-D particularly, may suggest how this herbicide fits into the enzyme picture.

The majority of enzymes consist of a non-protein portion (the prosthetic group or coenzyme) in addition to a protein part. The prosthetic group, which may be metallic or organic, is responsible for the activity of the enzyme, while the protein portion (apoenzyme) gives the enzyme its specificity. Many enzymes have the same prosthetic group but differ in their protein portion and thus differ in their specificity.

The chemical combination occurs between the substrate atoms and the prosthetic group, while the protein may serve to activate the substrate by a fleeting combination with it if their molecular architecture is suitable. If this molecular architecture is changed—either during the synthesis of the protein or after its formation—the activity of the enzyme is altered.

Each plant cell has its own complement of enzymes—over a thousand at least. Most are within the cytoplasm as its soluble portion. Other enzymes are bound to various particles located in the protoplasm—chloroplasts and mitochondria for example. The synthesis of enzymes is controlled by genes in the nucleus of the cell or by cytoplasmic units called plasmagenes. These are also formed under the influence of genes and may be thought of as master enzymes.

The mitotic irregularities which have resulted from 2,4-D treatment of the plant (18, 26) are evidence that 2,4-D makes its influence felt within the nucleus itself. It is logical to infer that the nuclear processes concerned with synthesis of enzyme proteins may also be interfered with and the molecular architecture altered. This means that the normal activation of the substrate is lessened or prevented.

A substance may change the activity of a "normal" enzyme by direct action on the prosthetic group or on the protein portion. Direct action of 2,4-D on the protein is indicated (25) by the quantitative and qualitative changes in protein brought about by treatment and also by the consideration of difference in effectiveness when used on different species. If we consider that speciation is dependent on specificity of proteins this difference in effectiveness becomes a variation in reactivity between the growth regulator and enzyme protein.

The growth regulator may have a molecular architecture similar to that of the substrate and thus be able to compete with the substrate

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for the protein portion of the complete enzyme. If the regulator-protein combination is stable the protein is masked and its ability to combine in transient fashion with the substrate to activate it will be lessened. Both enzyme and substrate may be blocked by different regulator molecules combining with the protein and with the substrate. The possible points of enzyme-substrate combination are decreased in number and the reaction slows. On the other hand an increase in enzymatic activity would result if the growth regulator facilitated the enzyme-substrate combination by first forming a substrate-regulator-enzyme complex with a lower energy of activation than the enzyme-substrate.

Some investigators have found that the application of 2,4-D results in an immediate increase of enzyme activity followed by a decrease. It is possible that small amounts of 2,4-D may act in the substrate-regulator-enzyme complex to speed activity. As the 2,4-D accumulates both the substrate and the enzyme may separately be saturated with the 2,4-D and the formation of the complex is prevented. The effects of 2,4-D on the apparent activity of phosphorylase, amylase, catalase, and peroxidase in Marquis wheat followed this pattern (32).

The regulator may also act directly on the prosthetic group or coenzyme, changing its state and so prevent its active association with the apoenzyme. There may be a combination of the regulator with the prosthetic group to give a more or less stable complex. The ability of the prosthetic group to combine with substrate atoms is thus decreased. Cyanides inhibit some enzyme reactions in this way.

One characteristic of 2,4-D is a disturbance of the normal processes of differentiation. The addition of indoleacetic acid antagonizes this disturbance and suggests that IAA insures normal development by polarized division in the meristematic cells (29). This auxin may act as a coenzyme and become fixed to cellular substrate by multipoint attachment. 2,4-D might compete for these substrates and thus decrease the auxin-substrate combination to a lesser or greater extent. The result would range from slight malformations to serve proliferation and death.

Substances which inhibit enzymatic action may do so by competing with the prosthetic group (or coenzyme) for the enzyme protein. For example sulfa drugs owe their effectiveness against certain bacteria to the fact that they are very similar to the vitamin which serves as the prosthetic group in certain respiratory enzymes of the bacteria. The sulfa drug combines with the protein to give a unit of no catalytic action and the respiration and growth of the bacteria are depressed.

In addition to direct action, the growth regulator may alter the enzymatic activity in an indirect fashion. It may, for example, change the pH and degree of hydration of the substrate. It has been shown that 2,4-D changes the amount of riboflavin, thiamin, nicotinic acid and adenine in plants (17). These members of the vitamin B group constitute the coenzymes of enzymes of hydrogen transfer (riboflavin in flavoproteins, nicotinic acid as phosphopyridine nucleotide in coenzyme 1), of phosphate transfer (adenine nucleotides as ATP

etc.), and of carbon dioxide liberation (thiamine in cocarboxylase). All these enzymes are closely associated with energy reactions in the plant. The application of low concentrations of 2,4-D increases the rate of respiration but high concentrations inhibit respiration (14). These observations together with the finding that the amount and quality of proteins and amino acids are changed by this herbicide suggests that the effect of 2,4-D on the activity of some enzymes may be brought about by increased or decreased vitamins for prosthetic or coenzyme function and a changed supply of amino acids for enzyme-protein synthesis.

The abundance of the end product of a reaction sequence may be influenced by blocking the sequence at some intermediate point or by removing such a block already present. For example in the sequence A —(1)→ B —(2)→ C if enzyme (1) were inactivated or the intermediate product B withdrawn by combination with an inactivator the production of C would be decreased and the apparent activity of enzyme (2) would be lowered. If such a situation already exists an activator might prevent this weakening side action. The rate of respiration of some plant parts is normally limited by the capacity of the phosphorylating system. Since low concentrations of 2,4-D increase respiration (14, 33) it may well be that the chemical affects this phosphorylative portion of the respiratory sequence. It has been suggested that the chemical actually participates in the phosphate transfer.

It has been shown that dehydroascorbic acid activates plant amylase while ascorbic acid, riboflavin, thiamine and calcium pantothenate inactivate it (16). This latter group also inhibits proteolytic activity. Variations in ascorbic acid and in the vitamin B group have been obtained in 2,4-D treated plants (31). This suggests that the effect of 2,4-D on amylase and proteolytic enzymes may be produced through its influence on other metabolites.

Changed metabolism may be the result of stimulated side reactions which yield products, which in their increased concentration, cause the metabolic change. One such effect has been ascribed to poisonous coumarin derivatives, the production of which is stimulated by 2,4-D (6, 13).

It was mentioned earlier that indoleacetic acid is concerned with the growth of a plant. This hormone is destroyed by an IAA oxidase system in which there are two components—a flavoprotein which produces hydrogen peroxide and a peroxidase which uses the peroxide to oxidize the IAA (8). Experiments have shown that lethal doses of 2,4-D decrease catalase activity and also slow growth (32). The enzyme catalase decomposes hydrogen peroxide into water and gaseous oxygen. Since there is less catalase activity more of the peroxide will be available to the peroxidase component for the inactivation of IAA, and decreased growth results. In cases where low concentrations of 2,4-D stimulated growth an increase in catalase was measured. This increased catalase competes with the peroxidase for the hydrogen peroxide, less IAA is inactivated, and growth is increased.

Some evidence points to a direct action on enzymes by 2,4-D but the majority of findings support the thesis that the effects of this herbicide on enzyme systems are produced indirectly in the ways suggested above.

Three very good reviews of numerous aspects of the physiological relationships of growth regulators have appeared in recent issues of Annual Review of Plant Physiology, Bonner and Bandurski's "Studies on the physiology, pharmacology, and biochemistry of auxins" (1), van Overbeek's "Agricultural application of growth regulators and their physiological basis" (27), and "Herbicides" by Crafts (3). Weintraub (30) discusses numerous aspects of the mechanism of action of 2,4-D.

Effect of 2,4-D on plant enzymes and vitamins

Enzyme	Plant	Dose	Effect	Reference	
Alpha-hydroxy acid oxidase	Castor bean seed		0	Hagen '49	(12)
Amylase, alpha	Virus tumor tissue	100 ppm	0	Brakke '52	(2)
Amylase,	Bean stem slices	10 ppm	Increase	Gall '49	(7)
Amylase,	Kidney bean	50 v/plant*	Stem: decrease Leaf: 0	Neely '50	(20)
Amylase, beta	Wheat tops	5 and 500 ppm	2 day: increase	Wort '53	(32)
Ascorbic acid	Buckwheat	10 v/plant	Leaf, stem: increase	Wort '50	(31)
		100 and 1000 v/plant	Leaf: decrease Stem: increase		
Ascorbic acid oxidase	Barley seedlings	10^{-5} M	Decrease	Miller '51	(19)
Ascorbic acid oxidase	Bean leaf	10^{-3} M	Decrease	Wagenknecht '51	(28)
Catalase	Tomato flower		Increase	Yakushkina '48	(33)
Catalase	Castor bean		0	Hagen '49	(12)
Catalase	Pea		Decrease	Goldacre '49	(10)
Catalase	Artichoke		Decrease	Galston '51	(9)
Catalase	Wheat tops	5 and 500 ppm	Increase	Wort '53	(32)
Glycolic acid oxidase	Bean leaf	10^{-2} M	0	Wagenknecht '51	(28)
Glycolic acid oxidase	Barley	10^{-4} M	Decrease	Miller '51	(19)
Indoleacetic acid oxidase	Pea		Increase	Goldacre '49	(10)
Invertase	Kidney bean	50 v/plant	0	Neely '50	(21)
Lipase	Wheat germ	5.6×10^{-2} M	Decrease	Kvamme '49	(15)
Lipase	Castor bean seed	$.03 \times 10^{-3}$ M	Decrease	Hagen '49	(12)
Nicotinic acid	Kidney bean	50 v/plant	Leaf: decrease Stem: increase	Luecke '49	(17)
Pantothenic acid	Kidney bean	50 v/plant	Leaf: increase Stem: decrease	Luecke '49	(17)
Pectin methoxylase	Kidney bean	50 v/plant	Increase	Neely '50	(21)
Peroxidase	Tomato		Flower: decrease Leaf: increase	Yakushkina '48	(33)
Peroxidase	Kidney bean	5.7 v/plant	Leaf protuberances: increase	Felber '48	(4)
Peroxidase	Pea		0	Goldacre '51	(11)
Peroxidase	Wheat tops	5 and 500 ppm	Increase	Wort '53	(32)
Phosphate enzymes	Tomato		Increase	Ravazzoni '49	(23)
Phosphatase	Corn and cowpea seedlings	1.5 ppm	Root: increase	Olsen '50	(22)
Phosphatase	Wheat tops	5 and 500 ppm	Decrease	Wort '53	(32)
Phosphorylase	Kidney bean	50 v/plant	Decrease	Neely '50	(21)
Phosphorylase	Wheat tops	5 and 500 ppm	Increase	Wort '53	(32)
Polypeptidase	Soybean		Leaf: decrease Stem, root: increase	Freiberg '52	(5)
Polyphenol oxidase	Castor bean seed		0	Hagen '49	(12)
Proteolytic	Kidney bean		Leaf: decrease Stem: increase Root: decrease	Rebstock '52	(24)
Thiamin	Kidney bean	50 v/plant	Leaf: decrease Stem: increase	Luecke '49	(17)

*v—microgram.

The effect of 2,4-D on a number of plant enzymes and vitamins is given in the following table. It is obvious that the effect differs from plant to plant and also in the various organs of a given plant. The age of the plant at time of application is important physiologically since the cells and their enzyme systems change with age and one would anticipate different responses—and these differences have been obtained. A number of the results were obtained by culturing tissue in 2,4-D solutions, some by adding 2,4-D to homogenates of plant tissue, and some by applying the chemical to the growing plant and testing plant tissue for enzyme activity at intervals after the application. It has been shown that a response may be reversed as time after treatment increases.

The data coming from such diverse investigations are hard to integrate and interpet but such data are indispensible for a clear picture of how herbicides affect enzyme systems and bring about the effects they do.

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Trends in Teaching Weed Control

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BEFORE discussing the subject of "Trends in Teaching Weed Control", let us consider the agricultural situation for a moment! According to agricultural statistics there is a trend towards larger farms. These can be operated most efficiently only by making economical use of equipment. It can also be said that farming is a business. Those operating farms are conscious of costs. Therefore, any weed control program that might be adopted would be favored principally because of its economic value. Farming is also becoming more scientific as we are now living in a scientific age. As farming becomes more scientific, those persons operating farms must have the ability to make use of new developments regardless of their own scientific tendencies.

As we look into the future, we must not forget that the population of this country is increasing rapidly and that agriculture will be called upon to produce more food to nourish the growing population. Since expansion of cultivated areas is not possible to any great degree, the increased production must come from improved farming practices. Consequently weed control will become more popular and farmers will learn the value of weed control and its influence on production.

Those who are interested in planning and carrying out educational programs in agricultural work keep in mind that farm operators and farm managers are busy individuals and are becoming more so as new scientific methods are being introduced and demands for increased production become apparent. Since they are busy individuals they will seek information through channels that take the least amount of their time. They may not find time to attend many meetings or may not be inclined to do so if they can obtain the information desired by reading publications, listening to the radio or watching television. Incidentally a recent survey found that more than 30 per cent of Indiana farmers have television sets. Here alone is a challenge to those who are interested in reaching the farmer.

WHAT IS THE WEED CONTROL SITUATION?

In the past several years, an abundance of weed control information has become available. This is the result of an abundance of research. The picture in this respect is vastly different from what it was some ten or more years ago when there were very few new developments in the field of weed control. Anyone at that time discussing weed control could only point out the advantages of timely cultivations, hoeing of weeds and the use of a few costly chemicals. Much of the recent information is of a technical nature and requires considerable study in order that it may be properly

applied. In the last ten years farmers have learned the technical names of many new herbicides and how to use them. They have learned that it is necessary to take precautions in applying these materials especially when they are used on crops. They have seen what might be called a miracle in the use of 2,4-D for selectively weeding corn, small grains and turfs. The educational program is over the hump, so to speak, as far as developing chemical weed control is concerned. I do not mean to say however that new techniques and new materials will not be developed in the future but they will not be too difficult to teach because farmers and other users have learned the principles of chemical weed control.

Farmers are not the only ones interested in weed control. Industrial firms, especially those in charge of utility lines, railroads and highways have weed control problems and rely upon research and educational agencies for their information. Many weed control problems are of public interest making it necessary to coordinate the program so as to satisfy all concerned. The general public is concerned about the destruction of certain types of vegetation.

WHAT SHALL WE TEACH?

During the last several years there has been a tendency on the part of those teaching weed control to emphasize eradication of weeds. I will predict that in the future we will be concerned principally with the control of weeds. Those concerned with weed problems will be principally interested in holding weeds in check so that they will not interfere with crop production or on non-crop areas so that they will not constitute a nuisance to the public. This does not mean we should abandon the idea of eradicating small infestations of persistent perennial weeds where such might be possible and practical to prevent further spread.

Since we are principally concerned with the teaching of adults, methods of teaching must stress the *how* rather than the *why* of what is being taught. Adults are living now. They have a problem to solve now. Therefore what is taught must be of immediate aid. This does not mean that reasons for so doing should not be taught. On the contrary often the most simple procedure of explanation is to tell why things happen as they do. Many of you are still curious regarding how 2,4-D kills plants. Merely stating that it kills weeds and how the material should be used is not enough. A discussion of this phase of weed control should include statements regarding the nature of 2,4-D, how plants absorb the material and if possible what physiological action takes place in the plant.

It is also apparent that community action is essential to weed control as weeds spread by various means from farm to farm and from community to community. An individual attempting to hold weeds in check is at a disadvantage unless others in the area are willing to cooperate and do their part. We must therefore teach the subject matter in such a way as to stimulate collective thinking and collective action.

WHO SHALL WE TEACH?

To be most effective an educational weed control program must reach all the people interested in the subject. In a long time program of teaching weed control the younger generation should not be forgotten. 4-H members, high school and college students should have an opportunity to learn the fundamentals of plant identification and control. It is these young people who will eventually be the leaders in their respective communities and it is they who will carry the responsibility of assisting in future educational programs. To this group fundamentals and principles should be stressed. Youth should be primarily interested in learning for the purpose of understanding principles. With the inevitable changing conditions, techniques which apply today are not as important to them as principles which they may apply in the future.

When teaching adults the teacher should recognize that there are two types of purposes dominating this group. One may be classified as the "action purpose", the other the "knowledge". The action group is interested in knowing how to get the job at hand done; the knowledge group is interested chiefly in knowing for the purpose of understanding. In the action group are leaders, farmers, dealers in materials and equipment, and others actively engaged in weed control. It appears logical to believe that it is in this group that greatest returns or adoptions of practices taught will be made because of the present interest of members of their group. They either have a weed problem to solve or are engaged in making a living which depends on the extent of activity in this field. Others are those whose interest is mainly that of a desire to learn and understand and they should not be neglected. This group usually is interested in the *why* rather than the *how* of happenings.

HOW SHALL WE TEACH?

We must use all means and teaching methods available to convey the message to those concerned with the problems of weed control. Changes in adult behavior and practices are affected by the number of contacts made. The degree that rural people are exposed to information through meetings, demonstrations, bulletins, news stories, radio talks, personal contacts and other teaching aids and devices will directly influence their acceptance of recommended practices. Some studies have shown that as the number of different types of contact to the same information increases from one to nine, the number of acceptances of the practice being taught increases from 35 to 98 per cent. This increase is very rapid as the contacts increase through the use of five to six different teaching aids. Repetition in a variety of ways and means is exceedingly important to learning.

Marsh and Aquatic Weed Problems in Wildlife Habitat*

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TO MOST people, the word *weeds* signifies pest plants of the farm, roadside, or other upland areas. However, weeds also occur on, under, or near water. Fifteen million dollars have been spent on a single aquatic nuisance in the South—the prolific water-hyacinth which clogs navigable streams and lakes with its growth. Hundreds of thousands of dollars have also been expended on control of the waterchestnut or water caltrop in the Potomac River. In addition, smaller-scale local campaigns are continuing against cattails, reeds, giant cutgrass, maidencane, alligatorweed, needlerush, lotus, rosemallows, willows, alders, buttonbush, and similar weeds that interfere with land use for recreation, irrigation, or other purposes. Since control of marsh and aquatic plants in wildlife habitat is an unfamiliar activity to most weed workers, broad aspects of its *what*, *why*, and *how* will be explained briefly.

The field is definitely a new one, mainly because the need for it has arisen only recently. Fifty years ago there was little occasion for weed control in wildlife habitat; at that time, there was an abundance of wild ducks, geese, and game fish and no shortage of suitable places for them to feed and breed. Since then, however, the picture has changed as expanding agriculture and industry have taken over more and more of the wetland habitat used by wildlife and, at the same time, increasing millions of Americans have sought healthful outdoor relaxation in hunting and fishing. Shrinking living space for wildlife, together with greater hunting and fishing pressure from growing human populations, has made it necessary to make the best possible use of wetland habitats that remain undrained. More specifically, marshes and ponds that are poor or only fair for wildlife must, if possible, be made more productive by replacing weedy growths with useful ones.

First, of course, it was necessary to recognize the weeds as such. Research on food and cover used by wildlife has supplied indications of which plants are valuable and which are not. Also, food-habits reports have made it evident that thousands of acres in marshes and ponds across the country are dominated by weeds that seriously limit productivity for game.

Public interest in improving of wetland habitats has grown rapidly in recent years as the need for it has become more apparent. Now, most State game commissions have established programs for development of wetland habitat and several have local projects on control of marsh and aquatic weeds. During the past two decades the United States Fish and Wildlife Service has conducted marsh and aquatic weed-control operations on thousands of acres on the

*Invitation paper presented at the First National Weed Control Conference, Kansas City, Mo., Dec. 8, 1953.

national wildlife refuges. Also, it has made investigations into weed-control procedures, both in fish ponds and waterfowl marshes. These studies have been summarized in publications (1,2) which present considerable detail on tested procedures and on particular herbicides and their dosages for specified plants. Accordingly, comments here will be confined largely to guiding principles and generalized aspects of control practices.

At this point it will simplify matters if the subject of controlling weeds in wetland habit is divided into two main parts: one dealing with fishing waters and the other with waterfowl habitat. Weed-control problems in these two realms are rather distinct, as illustrated by the fact that though dense beds of aquatics are often useful for waterfowls, they are generally undesirable in fish ponds. Not only do such growths snare fishing tackle and impede the use of boats, but they also tend to limit the production of game fish.

WEED CONTROL IN FISH PONDS

Commonly, though not always, the objective of weeding operations for fishery purposes is complete eradication of submerged aquatics other than algae. This may be accomplished either by the use of herbicides or fertilizers. In the Southeast, periodic treatment of ponds with inorganic fertilizers such as are used on farms has proved practical in controlling undesirable submerged vegetation. The fertilizer promotes production of planktons of so-called "bloom", consisting of millions of single-celled algae which shade-out other aquatics and also furnish food for fish, either directly or indirectly.

Effective use of herbicides on submerged aquatics requires measurement of water volumes in order to avoid dosages that would be fatal to fish. Sodium arsenite is regarded as the best general-purpose herbicide for fishpond weed control, though wearing of rubber gloves and observance of other precautions are advised in its use. This chemical kills most submerged growths at strengths of 2 to 5 parts per million but fish are generally not harmed unless the dosage exceeds 11 parts per million. Consequently sodium arsenite's usefulness on water weeds is equivalent to that of 2,4-D for land plants. Copper sulfate is widely used for combating filamentous and other undesirable algae.

WEEDS IN WATERFOWL HABITAT

Ascertaining the best way to control marsh weeds under various local conditions requires studies fully as complex and detailed as those on agricultural pest plants. Besides acquiring intimate knowledge on the weed and its ecology, there must be replicated tests on various control methods and materials and also determination of the most vulnerable stage for treatment. In addition, the replacement of the weeds by useful plants requires special study to determine what desirable species can succeed, how soon they can become established, and how long they can retain dominance. Actually, this is the most important part of the program for which weed control

operations are simply a preliminary step. Accordingly, efforts to control marsh weeds can be regarded as successful only, if they (1) are economically feasible and (2) enable effective replacement by desirable plants.

It should be emphasized at the outset that in many impounded areas one of the most practical ways of improving waterfowl food resources and of overcoming or avoiding weed problems is by effective management of water levels. In particular, there has been widespread success with summer drawdowns which expose mud flats for growths of wild millet, smartweeds, other native species, or cultivated crops, the seeds of which become readily available for waterfowl during fall reflooding. This practice has transformed many relatively barren areas into popular havens for waterfowls. High water levels maintained through winter and spring tend to drown out undesirable perennial weeds but in some places the drawdown may need to be omitted in alternate years in order to curb weeds that may survive the winter-spring submergence.

Herbicides used on marsh plants are largely the same as those employed on upland weeds. The most popular one is 2,4-D, applied in its various ester and salt formulations. On national waterfowl refuges in various parts of the country, 2-4-D has been sprayed extensively by airplane. Ammate and TCA have also proved effective on certain marsh weeds, the former having value for both woody and herbaceous species and TCA for coarse grasses. Other newer herbicides are undergoing tests on wetland plants at present.

Mechanical means of control such as mowers, discs, or crushing devices have proved effective under marsh conditions which permit use of such equipment. On numerous waterfowl refuges, they have made it possible for useful plants to replace extensive stands of weedy vegetation. Possibly mechanical methods could have even more usefulness if suitable equipment were devised for mowing operations in soft-bottomed marshes. Then, for example, widespread application might be made of a procedure that appears to offer the most effective and economical control of cattails, namely mowing at two particular stages of growth. Though herbicides have replaced floating mechanical equipment recently in programs against aquatics such as water-hyacinth and waterchestnut, it may be recalled that the biggest single victory against weeds inimical to fishing and waterfowling values was won by a flotilla of mowing devices operating on waterchestnut beds in the Potomac River.

So-called "combination treatments" frequently have special usefulness in controlling marsh weeds. Dual or multiple attacks may involve various combinations such as burning and spraying, burning and disking, mowing and flooding, flooding and spraying, or spraying followed later by another application of the same or different kind of herbicide. Generally, the first treatment weakens or "softens up" the plant for more effective destruction later. However, a somewhat different principle is involved in the practice of mowing weeds before raising water levels; drowning is more complete and rapid when emergent stems are absent.

An ounce-of-prevention policy seems particularly important in controlling weeds of wetland habitats. Watchfulness and alert action before invading weeds become well-established can avoid much effort and cost later. Millions of dollars could have been saved if, years ago, pest species such as water-hyacinth, waterchestnut, salt-cedar and alligatorweed had been prevented from spreading. Probably the best time to win weed wars is before they begin—by prevention.

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An Inexpensive Controlled–Environment Chamber for Herbicide Research[1]

CHARLES L. LEINWEBER[2] and WAYNE G. MCCULLY[3]

BRUSH species treated under field conditions have exhibited a variable response to growth-regulator type herbicides which cannot be explained by previous research findings. Light and temperature are known to influence the response of plants to these materials. Field observations have indicated that environmental factors such as relative humidity and soil moisture may also control to some degree the reaction of plants to herbicides. This chamber is being used to subject seedlings and small plants to controlled conditions of environment for evaluating the hypotheses suggested by field observations.

Several types of environment chambers have been described including the small cabinet of Granfield and Zinc (2), the converted cold-storage vault of Antoginnini (1) and the basement room used by Hamner (3). Granfield and Zinc used refrigeration and sulfuric acid to regulate temperature and humidity, respectively, but the cabinet accommodated only a single plant. Antoginnini controlled humidity using calcium chloride and an atomizer. Considerable quantities of desiccant would be required to service the projected experiments. Hamner maintained a relative humidity of 80 per cent with atomizers controlled by a hair-element humidistat. The desired temperature was obtained by thermostatic control of the entrance of cool outside air and electric heaters. The latter system does not permit the use of a wide range of relative humidities.

This controlled-environment chamber consists essentially of two parts: (1) a household refrigerator for cooling and dehumidification, and (2) a plant cabinet fitted with lights and automatic temperature and humidity apparatus (Figure 1).

Cooling and dehumidification are effected by circulating air within a baffled jacket enclosing the cooling element of the refrigerator. The jacket, three inches in width and 13 inches in length, is sealed to the cooling element to prevent moist air within the refrigerator being drawn into the system. Air temperatures within the jacket are lowered as much as 40 degrees F. Condensate from the cooled air either forms ice or is drained off as water. A pan under the dehumidification unit collects condensate from the external sur-

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A CONTROLLED-ENVIRONMENT CHAMBER

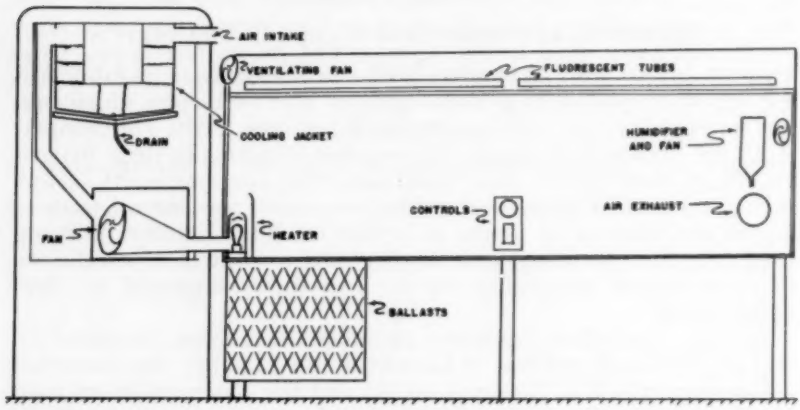

FIG. 1. Schematic diagram of a controlled-environment chamber consisting of a modified refrigerator for dehumidification and cooling (left) and the plant chamber (right) fitted with fluorescent lights and automatic temperature and humidity controls.

face of the jacket and water from within the jacket and drains it outside the refrigerator.

Circulation of air around the cooling element and into the plant chamber is accomplished by a 10-inch fan contained within the air system and mounted in the bottom of the refrigerator. A complete air change within the plant chamber is accomplished in 2.2 to 5.5 minutes, depending upon the resistance employed in the fan circuit.

All air entering the plant chamber passes through a heater consisting of six 100-watt incandescent bulbs shielded with a metal hood. The heater is controlled by a gas-bellows type temperature switch located in the plant chamber. Temperatures ranging from 75 ± 1 to 90 ± 1 degrees F. can be maintained using this method provided the outside temperature does not exceed 80 degrees F. A refrigeration unit of larger capacity and a better insulated plant chamber will provide greater versatility.

Air within the plant chamber is circulated using a six-inch fan. A water atomizer set in front of the fan and regulated by a humidistat and solenoid valve, similar to the system described by Henderson and Hunt (4), permits the use of relative humidities ranging from 35 ± 2 to 90 ± 4 per cent.

Illumination for the chamber is supplied by 40 forty-watt 4500 degree K white T12 fluorescent tubes mounted $\frac{1}{4}$ inch apart in two banks of twenty tubes each. Slimline 96-inch tubes would eliminate the dark spot in the center of the plant chamber caused by the decrease in light intensity at each end of the 48-inch tubes. Placing the tubes closely adjacent in a bank intensifies the illumination so that it is several times that measured from a single tube. Aluminum

foil resting on the tubes serves as a reflector and increases the illumination approximately 200 foot-candles. Single lamp, 0.8 ampere, resistance type ballasts serving individual fluorescent tubes are mounted on a panel outside the chamber. The ballasts are arranged in four rows of ten each. Each row of ballasts has a separate electrical inlet plug and connects to ten alternate fluorescent tubes in one of the banks.

Light intensity is measured at soil level using a Weston photometer. Full illumination provides 1200 to 1800 foot-candles, and 850 to 1000 foot-candles are obtained when half the tubes in a bank are lighted. Illumination should be checked regularly during use, since the lamp output decreases with time. Heat generated is effectively dissipated by circulating air around the tubes with a 10-inch, one-speed fan.

The plant chamber is of wooden frame construction 20 inches high, 111 inches long and 36 inches wide inside. The ends, sides and ceiling consist of double walls of clear plastic sheeting to provide insulation against the effects of outside temperatures. The condition of both plants and instruments can be observed without entering the plant chamber. The ceiling is comprised of two removable panels held in place by small screw jacks. Each of two removable wall panels held in place with level-type fasteners allows immediate access to either half of the plant chamber. Both ceiling and wall panels are fitted with weather stripping along the bearing surfaces. Plastic drop curtains fitted with arm holes are fastened over the opening normally covered by the detachable wall panels to prevent a sudden major change in the imposed environmental conditions while treatment is being made.

This environment-control system can be constructed at a cost of approximately two hundred and fifty dollars for materials. The major items of expense are the fluorescent fixtures and the humidity system. Should the plant chamber become contaminated it can be renovated or replaced at small expense.

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Accumulation and Distribution of TCA in Plant Tissues[1]

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AN UNDERSTANDING of the physiological and morphological responses of plant tissues to phytotoxic compounds makes possible a more intelligent approach to the problem of selecting and developing new herbicides for the control of weeds in growing crops. This area of investigation is frequently neglected in the haste to screen the many new chemicals which are reported.

Trichloroacetic acid (TCA) has been found to be a useful selective herbicide for the control of grass weeds in several crops, especially red and sugar beets.

The nature of the mechanism by which TCA brings about injury to plant tissues is not understood and thus we are unable to explain its selective toxicity to various plants. The differential toxicity of herbicides, in general, has been shown to be due to several factors (5). Differences in the amount of chemical absorbed, in some instances, accounts for the susceptibility of some plants and tolerance of others. Once the herbicide has entered the plant tissues, however, it is likely that selective toxicity may result from differences in the amount of chemical in active form required to injure the cells or from differences in the amount of the herbicide which reaches the region of injury. Thus, a quantitative estimate of the amount of herbicide accumulated in various plant parts may facilitate an understanding of the differential response which is obtained with various plants. It may also provide clues to the particular plant physiolcgical process which is being affected.

A few studies of the physiological response of plants to TCA have been reported. Barrons and Hummer (1) have found that while TCA may be absorbed through the leaves following foliar applications, it enters plants much more readily through the root system when the compound is applied to the soil. The influence of high levels of TCA upon the mineral content of leaves of apricot and prune trees was reported by Bruns (2). Soil applications in excess of 50 pounds per acre resulted in chlorosis of the leaves and produced small increases of iron, manganese, magnesium, copper, silicon, phosphorous, calcium, sodium, potassium, and chloride in these tissues. Miller (3) has studied the response of barley plants to TCA which was applied to the soil at the rate of one and two pounds per acre. The activity of the glycolic and ascorbic acid oxidase systems remained unchanged but the percentage of total nitrogen in the plants increased. More recently Rebstock, *et al,* (4) have shown an increase in respiration and a change of the plant constituents in wheat plants grown for a short period in soil treated with excessive amounts of TCA. The treated plants contained more protein, reducing sugars, and acid-

[1]This work was supported in part by a grant from the Wisconsin Canner's Association.

hydrolyzable polysaccharides and exhibited a change in the relative amounts of amino acids present when compared with plants grown in untreated soil.

MATERIALS AND METHODS

The plant species used in this study were snapbeans, millet, peas, and red beets. These species were selected because snapbeans and millet are very sensitive to TCA, peas are moderately sensitive, and red beets are tolerant of TCA.

The plants were grown in sandy loam soil contained in clay pots. The treatment with TCA was made at a time when the plants had made sufficient growth so that at least 50 mg. of tissue could be obtained for each plant organ to be tested. Thus, snapbeans which develop rapidly were sampled when they were about 6 inches tall and just beginning to bud. Beets, which develop more slowly, were allowed to grow until the largest leaves were about 3½ inches long. Millet was about 5–6 inches in height. Peas were about 6 inches tall and had three fully developed leaves when sampled. Fifty ml of water were used to dissolve the commercial grade sodium trichloroacetate supplied to each pot. Ten mg were added to each 3 inch pot and 12 mg were added to each 4 inch pot. The quantity of TCA contained in the individual plant parts was determined five days after treatment with a colorimetric method described by Tibbitts and Holm (6). Unless otherwise indicated below, each determination was made in triplicate on three or more individual plant samples.

RESULTS

Snapbeans at four weeks of age contained a large quantity of TCA in the terminal buds and young enlarging leaves. About 1,000 micrograms (one milligram) were recovered from each gram of fresh tissue of this origin. The terminal buds were completely stunted in these plants and the young leaflets had a wrinkled, water-soaked appearance. The roots, stems, and mature leaves were showing no injury at this time and the amount of TCA recovered from these organs was much below the level in the tips of the plants. The quantity of TCA found in the individual plant parts is shown in Table 1.

Table 1. Quantity of TCA recovered from tissues of snapbean plants (Micrograms of TCA per gram of fresh tissue)

	Terminal leaflets and terminal buds	Mature leaves	Stems	Roots
Snapbeans	938 ± 90*	99 ± 20	269 ± 48	94 ± 11

*Standard error of the mean.

TCA was not found in measurable quantities in the terminal buds and terminal leaflets of peas. The quantity of TCA found in the mature leaves of peas was 441 micrograms per gram of fresh tissue. By contrast, the amount of chemical which was stored in the stems

or being moved through the stems at this time was very small. There were indications of the presence of trace amounts of the chemical but measurable quantities were not recovered with this method. The amount of the herbicide recovered is shown in Table 2.

Table 2. Quantity of TCA recovered from tissues of pea plants (Micrograms of TCA per gram of fresh tissue)

	Terminal leaflets and terminal buds	Mature leaves	Stems	Roots
Peas	0	441 ± 41*	0	67 ± 13

*Standard error of the mean.

A further study was made to determine the amount of TCA which was present in fully expanded leaves of young pea plants. Three plants having five leaves each were selected for this determination. As may be seen from Table 3, the most mature leaf at the base of each plant accumulated less TCA than the leaves situated just above it. The second, third, and fourth leaves above, all of which were fully expanded, each contained about 400 micrograms of TCA per gram of tissue. The youngest fully developed leaf near the top of the plant contained only 246 micrograms of TCA.

Table 3. Quantity of TCA recovered from leaves at several positions on young pea plants (Micrograms of TCA per gram of fresh tissue)

	TCA recovered
Lower leaf	336 ± 12*
Second leaf	439 ± 18
Third leaf	426 ± 23
Fourth leaf	390 ± 23
Top leaf	246 ± 19

*Standard error of the mean.

The treatment of millet plants, which are extremely sensitive to small amounts of TCA, was delayed until the stems began to elongate. In general, only about 50 micrograms of TCA per gram of fresh tissue were found in the various organs of the millet plant. On the treated plants the outer blades encircling the growing point did not unfold and thus the normal upright extension of the stem was interfered with and severe malformation occurred. The quantity of TCA recovered from each tissue is given in Table 4.

Table 4. Quantity of TCA recovered from tissues of millet plants (Micrograms of TCA per gram of fresh tissue)

	Elongating stem and apex	Mature leaf blades	Roots
Millet	64 ± 8*	38 ± 3	46 ± 6

*Standard error of the mean.

Beet plants, which are very tolerant of TCA, also accumulated very small amounts of the chemical. The roots of the beets were about one-half inch in diameter at the time of treatment. Only about 40 micrograms of TCA were found in each gram of fresh plant tissue examined (see Table 5).

Table 5. Quantity of TCA recovered from tissues of beet plants (Micrograms of TCA per gram of fresh tissue)

	Terminal buds	Mature leaves	Roots
Beets	38 ± 8*	34 ± 9	38 ± 8

*Standard error of the mean.

DISCUSSION

For all of the TCA determinations in plant tissues, the chemcal was applied to the soil in which the plants were growing. This method of treatment was used in preference to foliar applications of the chemical because it was easier to obtain uniformity of treatment with the herbicide when using different types of plants. In a few trials, measurable quantities of TCA have been recovered from the terminal growing points of bean plants following foliar applications of the chemical to the lower leaves.

The determinations of TCA distribution for this study were made five days after treating the soil for it had been shown by previous studies (6) that this is sufficient time for maximum absorption. In the earlier studies TCA was recovered from bean plants within 12 hours after treatment and reached a maximum concentration in five days.

The young trifoliate leaves and terminal buds of beans, which contained large quantities of TCA, were severely injured. Injury to these tissues was produced in such a short time that it appeared the TCA might be affecting them by a direct, toxic action upon the cells. In previous experiments it was found that the primary leaves of bean plants accumulated a considerable quantity of TCA just following their emergence from the cotyledons. From the tests reported here, however, it is apparent that as the plants matured and began to bloom, only traces of the chemical were left in these early-formed leaves.

In contrast, to the situation in the bean, the young terminal growth of pea plants did not show symptoms of injury and it was impossible to recover TCA from these tissues. The more mature leaves of the pea plants contained large quantities of TCA. The amount of the chemical which is stored in the stems, or which moves through the stems at this stage of growth, is very small. These results on pea tissues are not in agreement with those obtained by Barrons and Hummer (1) with a qualitative test. Differences in the amount of TCA supplied to the plants, as well as differences in the age of the plant tissues, may account for this variation.

The quantity of TCA recovered from millet was surprisingly low in view of the severe injury suffered by the plants. In these and in tests of longer duration it was found that the symptoms developed very slowly, indicating that some gradual change was being brought about within the plant which produced a slow decline in the rate of growth.

Although the beet and millet plants accumulated about the same amounts of TCA in the various organs, the beets were not visibly affected by these levels while the millet plants showed excessive injury.

It has not been possible to determine from the experiments conducted to date whether the chemical found inside the plants is necessarily the trichloroacetic acid molecule as such. No attempts have been made to fractionate or isolate the active compound. It is entirely possible that the compound determined in the test may be a breakdown product of TCA or a complex of TCA with some organic constituent of the cells. Similarly, the absence of measurable quantities of TCA in a tissue does not preclude the possibility that the chemical entering the cells is metabolized or immobilized as a complex.

It is unknown at present, therefore, whether the tolerance to TCA is associated with an ability on the part of a plant to prevent absorption and translocation of the chemical to the young sensitive tissues, or whether the lack of injury may be due to an early metabolism of the compound or the formation of an inactive compound which is not detectable with the analytical procedure. It is clear, however, that the earliest and most severe symptoms of injury are associated with those centers where the chemical occurs in the greatest amounts.

CONCLUSIONS

Snapbean plants, which are very sensitive to TCA, accumulated large quantities of the chemical in the terminal buds and young enlarging leaves. Moderate amounts were found in the stems but only a small quantity was recovered from mature leaves and roots. Millet plants which are also very sensitive to TCA, contained only small amounts of the chemical in the terminal buds, stems, leaf blades, and roots.

Peas, which are moderately tolerant of TCA, were found to contain sizeable amounts of the chemical in the mature leaves. Little or no TCA was recovered from the terminal buds, stems, or roots.

Beets, which are highly tolerant of the chemical, contained only small amounts of TCA in any of the plant parts studied.

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Design and Analysis in Chemical Weed Control Research[1]

S. K. Ries[2] and W. C. Jacob[3]

In reviewing weed control literature, papers are frequently encountered in which the data have been presented without statistical evaluation. It is important for research workers in the herbicide field to be able to estimate the validity of their comparison just as it is for the workers engaged in fertilizer studies or any other phase of field research. Arithmetic means presented alone in a graph or in a table are extremely difficult to evaluate. Even though the author of a paper may have confidence in the significance of his data, it is difficult for the reader of a research report to evaluate the conclusions if an estimate of the experimental error is not presented. This may seem to place undue emphasis on statistical analysis itself. Yet in the relatively new field of weed control, few workers have had sufficient experience to judge the significance of differences of varying degree.

While it is true that a large number of results reported are of preliminary nature, it is important to have proper evaluation of these data since a research program may be based on the results of this preliminary work. Statistical methods are not only useful for evaluating the data, but also provide a means for extracting the maximum amount of information from an experiment through careful planning and adequate design.

It is the purpose of this paper to present certain principles which will permit herbicide investigators to obtain information with a greater degree of accuracy and efficiency.

Designing Experiments

Objectives

In any experimental plan there are certain essential principles that must be followed. A complete statement of the problem with the questions to be answered should be used to arrive at the design of the experiment. The questions to be answered are specifically involved in determination of the proper design. It is often helpful to list related questions that are not to be answered so that the boundaries of the inquiry can be better defined. This is especially helpful in summarizing the data from an experiment and in interpreting the results.

Selection of Treatment

Whenever possible treatments should be selected that will give clear answers to the questions asked in the statement of the problem. This may be achieved by defining the role of each treatment in relation to the problem and by specifying the conditions under

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which the treatments are to be compared. It may be desirable to include some treatments which are obviously not practical; e.g., high concentrations of expensive chemicals which may be necessary in studies on plant species tolerance. The number and type of check plots will depend on the objectives of the experiment. If it is desirable to determine the effect of the undisturbed weed population on the yield of a crop, it will be necessary to have a weeded and an unweeded check treatment. If yields are not taken or the effect of weed competition is not of interest, one check treatment is sufficient. This check treatment should be hand weeded after counting weed stands and mantained weed-free throughout the rest of the season. Some investigators are able to answer their questions adequately without check treatments in the experiment. Here again the objectives of the work are the deciding factors in the selection of treatments.

It may be necessary or desirable to include in the investigation a study of varietal response to environmental conditions, irrigation, cultivation, and insect and disease control. For this purpose the use of a factorial experiment is the only method available which will handle several variables simultaneously so that reliable results may be obtained. In certain cases several variables may be handled in separate tests and sufficient information obtained which will explain the effect of individual factors. However, to determine whether the level of a given factor A, such as temperature, influences the response to another factor B, such as chemical, both factors must be included in the same experiment. An alternative would be to run several experiments, each with a different level of factor A, but in most cases this would lead to more complications since it would probably involve locations, years and date of planting as well as the two factors presently under consideration.

SIZE AND SHAPE OF PLOTS AND NUMBER OF REPLICATIONS

The size of the individual plots in chemical weed control work is generally dependent upon the type of equipment being used. This may be modified in some cases by the data which are to be taken. If only weed counts or plant measurements are noted, the plot size in general may be smaller than if accurate yield records are needed. No work has been done on size of plot necessary for adequate evaluation of weed control work in row crops. It has been demonstrated with certain experimental equipment (12) that plots as small as 4 by 16 feet may be adequate with certain row crops.

Little work has been done on optimum plot shape for weed control experiments. However, yield data on field crops have demonstrated that if the orientation of the plots is in the direction of field cultural operations, long narrow plots will probably be more efficient than square plots. To reduce possible variation due to position in a field the long narrow plots should be grouped into square blocks or replications.

In evaluating the herbicidal properties of chemicals a single location is sufficient provided that enough replications are included to measure the response with the desired degree of precision. However,

if the objective is to test a chemical immediately prior to recommending its use in a geographical area, then several locations scattered throughout this area should be considered as replications. The interaction between chemicals and locations will be used as the error term for testing significance of differences.

Further discussions of these points can be found in Cochran and Cox (3), Kempthorne (9), and Fisher (6, 7).

GREENHOUSE STUDIES

Since considerable work on weed control is done in the greenhouse, it seems worthwhile to mention some common difficulties which may be involved. To investigate the effect of temperature on the response of a single crop to chemicals the usual procedure is to use one greenhouse for each temperature investigated, and a number of replications of the chemical treatments in each house. The major difficulty with this set-up is that there is no replication of temperature and the only thing that is being measured between the houses is whether there is a different effect of the houses on the chemicals. Whether this is due to temperature or to the house construction will be impossible to determine from this particular experiment. The only manner in which temperature effects can be tested adequately is to have a number of houses so that at least two can be run at each temperature to give adequate replication. An alternative would be to re-run the experiment randomizing the location of the temperature with respect to the houses for each run.

A more adequate discussion of this topic can be found in a recent paper by Federer (4).

PLOT LAYOUT

The actual layout of plots in the field for weed control experiments usually follows standard practice for other types of field experiments. Numerous designs are available and may be used for weed control tests. For a complete discussion of this the reader is referred to the recent book by Cochran and Cox (3).

For single factor experiments the most useful design is a randomized block. With factorial experiments more complex designs are usually advisable. One of the most useful designs for factorials is a split-plot in which certain factors such as the mechanical considerations of handling the experiment in the field, are chosen to represent main plots and sub-plots.

The usefulness of the factorial experiment designed in split-plot layout can be illustrated by an experiment dealing with the effect of time and method of application of two types of Stoddard Solvent to celery (10). The problem of primary concern was to determine which time of application was best from the standpoint of weed control and lack of injury to the celery. Also of interest was whether a combination of the treatments at different times would produce better or poorer results than a single treatment at one time.

Seven different times or combinations of times of application plus an untreated check were used as the smallest plots in a split-plot

design. The above treatments were arranged in larger blocks which permitted a comparison of methods of application. The objective of this was to determine whether an over-all spray would influence the results obtained at different times of application as compared to a spray directed only at the base of the plant. Since it was known that there was a marked difference between toxicity of a high and a low aromatic Stoddard Solvent and the primary interest was the interaction with the other factors, the largest split was assigned to percentage aromatics.

There were two levels and three replications of the split for percentage aromatics. These in turn were split into two plots for method of application which contained the times of application. The greatest accuracy of testing was for the eight times of application with decreasing accuracy for method of application and percentage aromatics. The single degree of freedom comparisons for this factorial are presented in the analysis of variance form in Table 1.

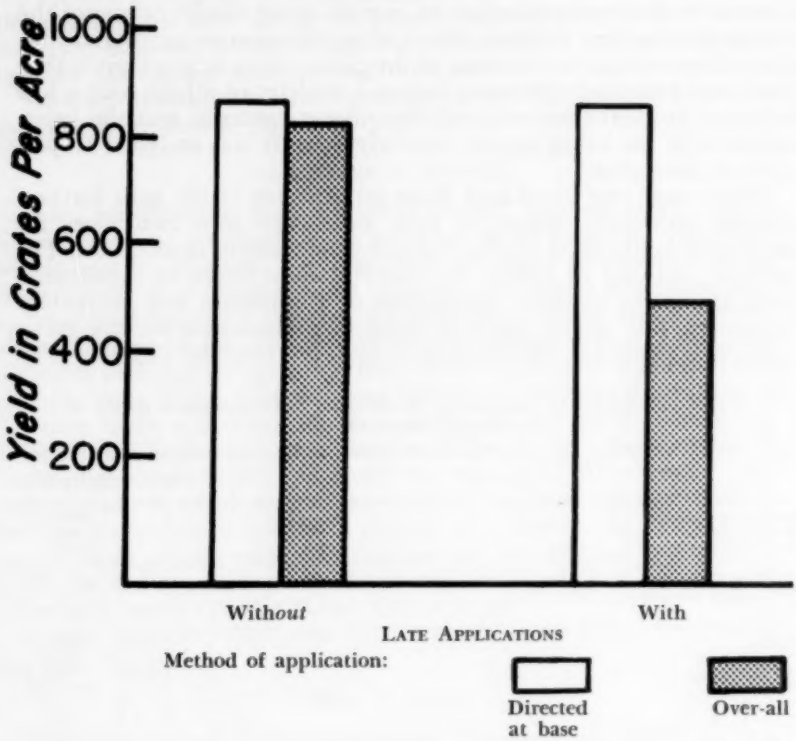
Table 1. Analysis of variance of yields from post-emergence sprays of Stoddard Solvent on celery.

Source	DF	Yields M.S.
Percentage Aromatics	1	846.0
Replications	2	11.8
Error a	2	202.5
Method	1	2677.0**
Percentage Aromatics × Method	1	17.0
Error b	4	44.8
Early	1	25.0
Mid	1	2.0
Mid × Early	1	8.0
Late	1	2062.0**
Late × Early	1	1.0
Late × Mid	1	13.0
Late × Mid × Early	1	68.0
Percentage Aromatics × Time	7	26.0
Method × Early	1	14.3
Method × Mid	1	49.6
Method × Mid × Early	1	147.5
Method × Late	1	1881.5**
Method × Late × Early	1	11.3
Method × Late × Mid	1	110.5
Method × Late × Mid × Early	1	12.8
Percentage Aromatics × Method × Time	7	31.0
Error c (56–1 for missing plot)	55	37.9
Coefficient of Variability		14.7%

**F value significant at 1% level.

The high degree of significance of late applications, method of application, and the interaction between method and late applications is brought out markedly in this test. All treatments which received the late application were severely injured. If treatments received no late application there was practically no injury to the crop. Because of the nature of the factorial design it was possible to show definitely that the only treatment which was affected by method of application was the late treatment. The interaction between method of application and late treatment is illustrated in Figure 1. In this case it can be seen that with late application an overall spray reduced the yield markedly whereas a directed basal spray did not.

FIG. 1. The effect of time of application on yield as influenced by method of application.



Without late applications no yield reductions were obtained from either method of application. It is interesting to note that for this particular interaction the data from 96 plots were reduced to four numbers tested with a single degree of freedom. This gave a high degree of precision for this comparison.

Another example of a split-plot experiment is cited to illustrate a difficulty with check plots. In this test, which has been reported in a previous paper (11), a study was made of the effect on yields of fungicide, time of treatment, and two rates of three chemicals plus a check plot. In this case the major plots were fungicides divided for time of application, each time was further divided into the chemicals and rates and a check plot. When an analysis of variance was run on these data in an ordinary manner using straight forward split-plot procedure, the time of treatment differences turned out to be non-significant. This was unexpected since field observations had indicated a considerable difference from time of treatment. However, an explanation is obvious from the means presented in Table 2. The check plots, which did not differ with respect to time of application, since no chemical was applied, were averaged with plots which

showed differences for time of application. If the data were analyzed eliminating the checks plots from the totals for time, much larger differences occurred between time of application as may be seen from the second series of totals at the bottom of Table 2. This is the manner in which the experiment was analyzed and reported (11).

Table 2. The effect of time of application on yield of tomatoes from post-emergence applications of esters of 2,4-dichlorophenoxyethanol.

	Chemical	Rate in lbs./acre	Time of applications		
			Early	Late	Early and late
1	Crag 1	2	170	163	137
2	Crag 1	4	155	177	132
3	6036	2	187	202	174
4	6036	4	166	212	144
5	Check		196	209	222
Time totals with check			874	963	809
Without check			678	754	587

This difficulty would not have been encountered in this experiment if time of application had been the smallest plot in the experiment instead of one of the major plots. Then the check plots would not have interfered with the comparison of time.

OBSERVATIONS

The type of observations to be made in a weed control experiment depends on the nature of the investigation. The usual observations are crop and weed growth measurements or ratings, weed counts, crop yields, and objective or subjective quality evaluations. One type of observation, which is not used extensively, is the ranking of crop growth or weed control. This implies that each treatment within a replication is ranked, assigning the best treatment a *1*, the second best a *2*, and so on through the full list of treatments for a given replication. These data may then be analyzed by analysis of variance procedure following transformation which will be discussed in a later section. Such a ranking procedure might be adaptable in situations where wide differences in weed population or crop growth seem to occur between replications.

The problem of using weed counts or weed ratings seems to be one of personal choice. It should be pointed out that percentage of weed kill is not nearly as important as the number and kind of weeds left in the plot. For this reason a rating system seems to have advantage over weed counts because the ratings actually take into account the size, vigor, and kind of weeds as well as relative number. Weed ratings are much easier and faster to make than counts.

Before final evaluation of a chemical can be made, crop yields must be taken. It is important that final evaluation be made under a variety of environmental conditions which may be encountered in the ultimate use of the chemical.

The quality of a crop, as it is affected by chemicals, is a very important phase which is now being investigated. It has been learned

from experience that many efficient chemicals used in agriculture for insect or disease control may have a lasting effect on the quality of the crop and it is imperative that the investigator know these factors before he proceeds to make any recommendation concerning specific chemicals.

If an objective test for the quality of the crop is available it should be used. If none is available then it will be necessary to set up a taste panel to evaluate the quality of the treated crop. It is not possible to go into the details in the course of this paper but it should be pointed out that the sampling procedure used for quality evaluation, as well as for chemical determinations, is extremely important. The validity of the conclusions rests primarily on the adequacy of the sampling procedure. The best chemical methods or the best taste panel methods will be ineffective if a representative sample or samples have not been taken. For further information the reader is referred to Bradley (2).

It is often of interest to know how one kind of observation may be associated with another kind. For example, weed control ratings and top injury ratings were made on potato plants and these ratings were combined by multiplication and correlated with final yield records of the potato crop (8). A correlation coefficient in excess of .95 was obtained. This indicated that the weed control and the injury ratings of the crop were accurately estimated and influenced the yield markedly.

Analysis of Data

In most cases data are analyzed following analysis of variance procedure. This may be modified to fit special designs or special factorial experiments. In many cases, however, transformations are necessary before analysis of variance may be used. In those cases where observations seem to have a range which is proportional to the mean, logarithmic transformation should be used. This is applicable to certain growth measurements. For example, if the chemical severely inhibits growth of a root or a shoot, there will be very little variation between the extremely short roots and considerable variation between the longer ones. If differences between observations or ranges when squared appear to be proportional to the means, a square root transformation should be used. This may occur if the data are discrete numbers or intergers such as weed counts. A full discussion of this may be found in papers by Bartlett (1).

If the ranking system mentioned earlier is being used then the ranks may be transformed for analysis of variance by use of Table XX in Statistical Tables by Fisher and Yates (7). Little investigation has been done into the necessity for transforming ratings. There may be situations where this is necessary and care should be exercised to make certain that ratings are transformed in those cases where it it needed.

Summary

Certain principles have been reviewed in this paper which it is hoped will aid weed control investigators in obtaining information.

More attention should be given to testing the reliability of data as well as to the design of experiments so that data obtained are more reliable. The concepts which have been reviewed are not new. It is felt, however, that a more extensive use of these methods in weed control research is desirable.

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Blended Solvents for Control of the Submersed Water Weed Naiad in South Florida[1]

JOHN C. STEPHENS, A. L. CRAIG and CHAS. C. SEALE[2]

THE SOUTHERN naiad, *Najas guadalupensis* (Spreng.) Morong. is a submersed water weed commonly infesting water control systems in south Florida, especially in the areas underlain by calcareous deposits where the canal waters are mineralized. Dense growths of this plant appear to have become more prevalent in recent years following the removal of water hyacinths by the use of 2,4-D.

This rapidly growing weed greatly retards the flow of water in drainage systems and endangers valuable crops and livestock in this region where the terrain is flat and storm rainfall is heavy. It also hampers irrigation in the same systems during the annual dry season.

Mechanical methods in use at present for controlling naiad have the disadvantages of being expensive and of only slightly inhibiting the regrowth of the plants (1).

Chemical methods for the control of this weed have shown promise of being more effective and less expensive than present mechanical techniques (1,2, 3, 4, 5). An experimental aromatic solvent, WS-1492, was found to be satisfactory for controlling naiad in south Florida (6). This formulation was not released by the manufacturer for general use due to military demands for highly aromatic oils and their derivatives since 1950.

A study to find an available substitute equal or superior to WS-1492 was initiated in 1951. This work has been carried out in two phases: 1) pilot or screening tests were conducted in the greenhouse to obtain rapid evaluation of samples of many potential herbicides; 2) field trials were made with those materials that showed promise in the screening studies and which appeared to be available for this area at reasonable costs.

GREENHOUSE STUDIES

Materials screened in the greenhouse tests were secured from such sources as chemical manufacturers, petroleum processors, and fuel gas plants. The products tested included 15 aromatic solvents and oils, 10 aliphatic hydrocarbons, 9 chlorinated hydrocarbons, 4 wood oils, and 21 miscellaneous commercial pesticides.

Tests showed that two non-ionic surface active agents were satisfactory emulsifiers for herbicides tested when used at a 5 per cent

[1]Contribution from the Florida Everglades Agricultural Experiment Station, in cooperation with the Central and Southern Florida Flood Control District and the Agricultural Research Service, U. S. Department of Agriculture.

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emulsifier-oil concentration by volume. These emulsifiers were used in all tests at this concentration.

Healthy specimens of naiad plants were transplanted in 3 to 4 inches of ditch silt in the bottoms of glass battery jars holding about three gallons of water. The plants were allowed to take root and grow for about one month. At the end of this period only jars containing vigorous and healthy plants were used for testing. Untreated control jars were observed along with the treated jars for the duration of the test. The herbicides were injected under water in the jars with a graduated hypodermic syringe using sufficient pressure to obtain proper emulsification. In an attempt to simulate conditions in the field where there is usually some movement of the ditch water, the jars were flushed by the addition of fresh water one day after the herbicide application and at weekly intervals thereafter. The treated plants were inspected and results noted at weekly intervals. The final evaluation of the degree of kill and of decomposition of the naiad was determined four weeks after application of the herbicide.

The results of the greenhouse tests indicated that many of the materials might offer satisfactory control of naiad under field conditions. In general the low boiling hydrocarbons, the highly aromatic solvents, the chlorinated benzenes, and several blends of these materials gave good results. The hormone and the soil sterilizing types of herbicides were completely ineffective.

FIELD TESTS

A field test of potential herbicides selected from those showing promise in the screening studies was performed in heavily infested ditches in a citrus grove west of Ft. Lauderdale, Florida, in April and May 1953. Test plots 100 feet long separated by 100-foot untreated guards were laid off in three parallel quarter-section ditches, of about 30 square feet cross-section, to permit replication in triplicate for each treatment.

Since many of the materials have flash points below the normal air temperature, they were applied with a special pressure applicator using carbon dioxide as a propellant. The herbicide was transferred from the pressure tank at about 30 pounds per square inch through neoprene hose to an application wand bearing three spray nozzles. The materials were applied to give a uniform, predetermined concentration by lancing this wand through the naiad and related growth to the bottom of the ditch. (Figure 1.) This rather laborious method was used primarily for an evaluation of the herbicidal properties of the materials and may not be of particular value for large scale commercial usage.

Previous studies for underwater weed control suggested the value of using emulsifiable herbicides with specific gravities of about 1.0 to increase the emulsion stability and to increase plant contact time, thus possibly permitting a reduction in the emulsifier-oil ratio, and also the total amount of herbicide required. Therefore, these tests were designed so that the effectiveness of the undiluted oils, at their normal specific gravities, could be compared with their effectiveness

FIG. 1. Experimental application of a blended herbicide using a lance-type hand applicator in a water control ditch heavily infested with southern naiad. Treated portion showing milky emulsion at left of boat, untreated ditch showing dense growth of weed to right. Herbicide used was a heavy, polychlorobenzene dissolved in a light aromatic solvent with 5 per cent non-ionic emulsifier to produce a resultant oil with a specific gravity of 1.025. This proved superior to the lighter straight solvent herbicides.

when blended with dissolved chlorinated benzenes to produce a fortified mixture having a specific gravity near that of water.

The commercial polychlorobenzene (PCB) mixed with the solvents and used in these tests had the following composition:

Component	*Content*
Dichlorobenzenes	2.2%
Trichlorobenzenes	22.8
Tetrachlorobenzenes	57.6
Pentachlorobenzene, hexachlorobenzene, and high boiling residue	17.4
	100.0%
Specific gravity	1.494

It had been noted that a portion of the heavier chlorobenzenes crystallized out of the PCB at the prevailing air temperature of 80 to 90 degrees F.; therefore, the commercial product was diluted with 15 per cent by volume of technical orthodichlorobenzene to reduce the crystallizing temperature. The resultant product was readily soluble in all of the oils and solvents tested.

A list of herbicides with rates of application, ASTM D56–36 flash points by Tag Closed Tester, and specific gravities appear in Table 1.

Table 1. Composition, rate of application, flash point, and specific gravity of naiad herbicides tested at citrus grove.

Treatment	Approximate composition	Rate of application	Flash point	Specific gravity
		ppm	°(F)	
1	Light Oil—95% Monsanto L Emulsifier—5%	200	below 16	0.88
2	Light Oil—78% Monsanto PCB—17% Monsanto L Emulsifier—5%	200	22	1.025
3	Tar Oil—95% Monsanto L. Emulsifier—5%	200	46	0.88
4	Tar Oil—78%, PCB—17% Monsanto L. Emulsifier—5%	200	42	1.025
5	Drip Oil—95% Triton X-155 Emulsifier—5%	200	37	0.87
6	Drip Oil—74%, PCB—21% Triton X-155 Emulsifier—5%	200	47	1.025
7	Amsco HT Solvent—95% Triton X-155 Emulsifier—5%	200	194	0.95
8	HT Solvent—77%, PCB—18% Triton X-155 Emulsifier—5%	200	above 210	1.20
9	Emulsifiable Trichlorobenzene (Product of Allied Chemical. Composition unknown)	200	above 205	1.40
10	HT Solvent—41% Drip Oil—41% PCB—13%, Triton X-155 Emulsifier—5%	200	60	1.025
11	Emulsifiable WS-1492 (Product of Esso. Composition unknown.)	200	92	0.87
12	Emulsifiable, WS-1492—77% PCB—22%, Monsanto L. Emulsifier—1%	200	99	1.025
13	Phillips Aromatic Solvent D—95% Triton X-155 Emulsifier—5%	200	below 15	0.83
14	Phillips Aromatic Solvent D—67% PCB—28% Monsanto L Emulsifier—5%	200	below 20	1.025
15	Phillips Aromatic Solvent D—95% Monsanto L Emulsifier—5%	400	below 15	0.83
16	Phillips Aromatic Solvent D—95% Monsanto L Emulsifier—5%	800	below 15	0.83

The emulsifiable light oil, tar oil, drip oil, WS-1492, and Aromatic Solvent D (Treatments 1, 3, 5, 11, 13, 15, 16) all rose to the water surface soon after application but stayed in emulsified form long enough to give adequate contact, quick knock-down, and good kill. However, these same products when combined with PCB (Treatments 2, 4, 6, 12, 14) remained suspended in the water for a much greater length of time and appeared to give better, although slower, control than the unmodified products. The emulsifiable trichlorobenzene (Treatment 9) sank rapidly to the bottom and gave a slow but effective kill. The relatively high boiling aromatic HT Solvent and its heavy blends (Treatments 7, 8, 10) affected the naiad slowly. These observations indicate that the lower the boiling point of the

herbicide, the more rapidly it will reduce turgor in the submersed weeds, causing them to settle to the bottom of the ditch and opening the channel for flow. On the other hand, the heavier ingredients with higher boiling points seem to have a more lasting effect in inhibiting new growth, although the initial effect may be less rapid. Table 2 shows the average rated effect of each treatment judged by the percentage of open channel observed at intervals of 4, 5, 17 and 23 weeks after application. Treatments shown coupled, as numbers 1 and 2, contrast the results obtained from straight and fortified mixtures with different specific gravities.

Table 2. Average rated effects of herbicide treatments at citrus grove showing per cent of open channel at time of observation.

Treatment	4 weeks	5 weeks	17 weeks	23 weeks
	May 27, 1953	June 4, 1953	Aug. 17, 1953	Sept. 30, 1953
	%	%	%	%
1	66	46	44	38
2	74	86	80	66
3	66	60	60	46
4	66	86	74	66
5	66	80	50	42
6	80	80	80	90
7	50	30	30	66
8	54	46	80	72
9	74	64	80	88
10	74	70	76	84
11	66	74	66	78
12	80	86	74	72
13	66	86	64	52
14	94	86	60	66
15	100	70	70	70
16	100	80	66	70

A large scale field test was performed in September 1953 in a 2,000-foot ditch of about 25-square foot cross-section at the University of Florida's Plantation Field Laboratory, west of Ft. Lauderdale, Florida. The southern naiad and a few related weeds such as *Potamogeton* had flourished in this ditch in spite of the relatively high velocity of water normally passing through it to supply an irrigation pump. Flow and slope measurements made just prior to the herbicide application showed the water gradient required for a flow of 4500 gallons per minute was 28 inches per mile.

The herbicide, a solution of Aromatic Solvent D and PCB with 5 per cent Triton X-155, proportioned to give a specific gravity of 1.025 for the mixture, was applied at 200 ppm by volume. This low boiling solvent formulation was used to obtain quick kill.

The carbon dioxide propelled pressure application equipment was mounted in a flat-bottom, shallow-draft boat propelled by a powered air screw, typical of those used for recreation and recon-

naissance in the marshy areas of south Florida. A spray boom, with nozzles suspended on flexible hose and discharging several inches below water surface, was mounted across the bow of the boat as shown. (Figure 2.) A side-view of the equipment showing a standard

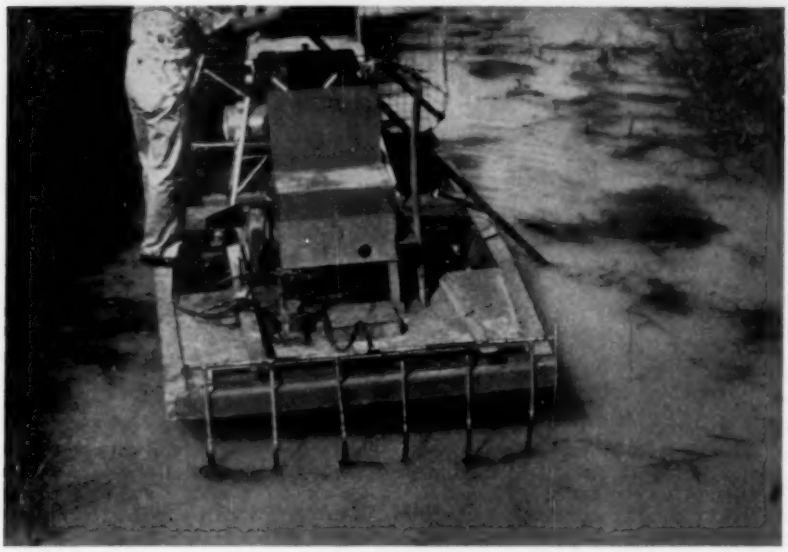

FIG. 2. Front view of airboat with underwater flexible spray nozzles attached. This outfit was successfully used to apply blended herbicides in the irrigation supply ditch at the University of Florida's Plantation Field Laboratory. Use of air screw enables boat to glide over heavy submersed aquatic growths and flex lines allow dispersion of oils under water with minimum fouling of nozzle lines.

CO_2 medical flask with attached regulator which reduces the gas pressure on the herbicide in the pressure tank to approximately 50 p.s.i. is shown. (Figure 3.) From the pressure tank, neoprene hose conducts the herbicidal mix through a hand control valve, shown mounted on the side of the driver's seat, and hence to the header pipe and six discharging nozzles. The intense turbulence created by the air blast and the wake from the boat at a speed of about five miles per hour thoroughly mixed the herbicidal emulsion throughout the ditch cross-section. The rapidity with which the oils can be applied even in ditches completely choked by dense growths of the naiad indicates that this rig, or an adaptation thereof, may have use for commercial applications.

The quick knock-down and kill resulting from this application was spectacular. Within 24 hours after treatment the water gradient was reduced from 28 to 1¼ inches per mile, and the value of Manning's "n" was lowered from 0.15 to a normal 0.023. The naiad completely disintegrated within 10 days.

Other tests were performed on naiad growing in field ditches dug through organic soils at the Everglades Experiment Station in the

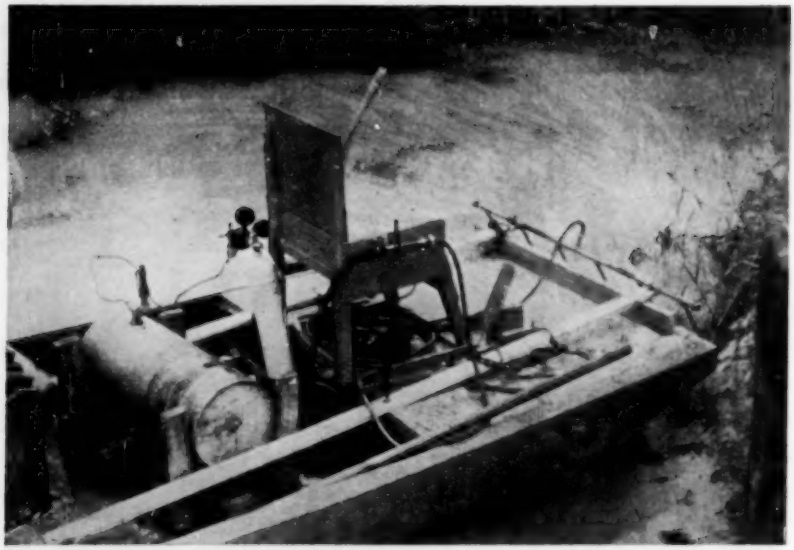

FIG. 3. Side view of experimental CO_2 pressure spray used for applying herbicide with low flash points. For commercial application, medical flask would be replaced by standard size flask holding 440 cu. ft. of gas at one atmosphere. Milky color of water is due to emulsified blended herbicide applied at a rate of approximately 200 ppm.

fall and winter of 1952. The three treatments used were "regular" leaded gasoline and trichlorobenzene blended to a specific gravity of 1.0 applied at 400 ppm; the same materials blended to a specific gravity of 0.95 applied at 125 ppm; and HT Solvent and PCB blended to a specific gravity of 1.15 applied at 100 ppm. Both gasoline treatments gave adequate control of naiad for a period of about five months. Retreatment with the HT Solvent and the PCB mix gave six months of additional control. Vegetable crops grown adjacent to these ditches and sub-irrigated from them were not affected by the herbicides.

Several different gasolines have been used in these studies and all produced satisfactory kill and decomposition of the weeds. However, because of the varying composition found from time to time in the commercial products the results cannot be predicted with certainty.

POSSIBLE HAZARDS

Since several of the products tested are unrefined, the possibility of their toxicity to field crops which are irrigated from treated canals or to livestock which might be watered from a treated source should be considered. The most likely opportunity for the introduction of toxic materials is in the appearance of phenols and related compounds in the drip oil, light oil, and tar oil, all of which are gas manufacturing by-products. Although there is no evidence that the agricultural use of water containing typical concentrations of these

herbicides is dangerous, plant toxicity, seed germination, and animal toxicity studies are being made.

Preliminary animal toxicity tests, of eight weeks duration, observed by a veterinarian from the State Livestock Commission, showed no abnormal condition resulting from giving water treated at 600 ppm to two corralled steers weighing 550 lbs. each. These cattle were given treated water for alternate weeks using 1) Aromatic Solvent D, a low boiling solvent; 2) Xylene, a medium boiling solvent; 3) HT Solvent, a high boiling solvent; and 4) drip oil, a gas manufacturing by-product, all of which were fortified with PCB and emulsifier. Both animals disliked the water and reduced their intake to about one to two gallons per animal per day. It was evident that had uncontaminated water been available the animals would have drunk this in preference to the treated supply.

Greenhouse tests conducted in cooperation with the horticulturist at the Plantation Field Laboratory showed that young corn, snap beans, and tomato plants were not injured by continuous subirrigation for one week with the above herbicides at 200 ppm.

All observed aquatic life was killed by the herbicide applications whenever the concentration reached approximately 50 ppm. However, within a few days when the water had cleared, it appeared that the plankton ratio was up and fish migrated from other canals in seemingly increased numbers. The complete snail mortality suggests that satisfactory control of water weeds and of snails acting as obligatory intermediate hosts to livestock liver flukes may be obtained with one or two applications of these herbicides.

Since many of these materials have low flash points, precautions similar to those followed in handling gasoline should be observed while transporting, mixing, and applying them. Although no fire hazard exists from these materials after emulsification in water, the low flash point materials will ignite readily if they are spilled on the surface of water whether they contain emulsifier or not.

Although none of these products has proved to be noxious to humans after reasonable exposure, it has been observed that prolonged breathing of concentrated fumes may cause nausea, and extensive skin wetting by chlorinated benzenes and highly aromatic solvents temporarily produces an irritating burn.

COSTS

The cost of ditch treatments with herbicides must compete with mechanical cleaning costs. The cost of redredging with draglines runs from $250 to $350 per mile on average-sized farm laterals and ditches in the Everglades area. This method has the advantage of cleaning the ditch of sludge, silt and other detritus and ordinarily is required at intervals of from 1 to 5 years regardless of vegetative conditions. However, reproduction of the southern naiad and related plants following redredging is very fast and regrowth to a stage where flow is almost completely blocked has been observed in a period of only six weeks. This fact, plus the high cost, has largely ruled out this method as a regular maintenance practice for weed control.

Dragging is cheaper but removes only the light or submersed weeds, and regrowth is fully as rapid as with redredging. The plants are not decomposed, and disposal of the bulky mass of material often presents a formidable problem. Too, many of the water control ditches in this area are bordered by fence lines or dense growths of brush and are crossed by many intercepting ditches so that it is not feasible in such cases to pull drags along the channel.

Exact costs for herbicidal treatments for this area cannot be determined until the method becomes prevalent enough to determine mixing, distribution and application costs. However, judging from the approximate cost of the raw materials which compose the blended herbicides, a reasonable estimate can be made. Fuel gas by-products such as drip-oils and light-oils now sell from 18 to 26 cents per gallon, depending upon their degree of refinement. Technical grade aromatics in the medium boiling xylol class can be obtained in tank car lots from refineries at delivered prices in the Miami area of from 40 to 45 cents per gallon.

Higher boiling aromatics, such as HT solvent, are somewhat cheaper, running about 30 cents. The technical grade chlorinated benzenes, such as orthodichlorobenzene and trichlorobenzene, sell wholesale for about $1.30 to $1.50 per gallon. The unrefined PCB, such as was used in these studies, is a by-product and consequently no price has been established for this area. The predicted delivered price in tank car lots is from 60 to 95 cents per gallon, depending on the quantity and the degree of filtering required to remove undissolved fractions.

Thus, based on ingredient percentages given in Table 1, the raw material costs for aquatic herbicides with specific gravity ranging from 1.0 to 1.025 would run from 26 cents for the blend of crude gas plant solvent plus unrefined PCB to 65 cents for a refined highly aromatic solvent of the xylol class mixed with technical grade chlorinated benzenes. Use of 5 per cent of a non-ionic emulsifier would add approximately 15 to 20 cents per gallon to these figures resulting in a total raw material cost of from 40 to 85 cents per gallon.

Estimates based on reasonable values of similar products suggest that the cost of formulation and distribution will run from 100 to 200 per cent of the raw material cost, depending upon volume demand. It would appear reasonable to assume that a satisfactory product could be sold for an average price of $1.25 per gallon if there were sufficient demand. Volume distribution might lower this estimate. Cheaper or more expensive blends could be mixed if desired to suit specific conditions.

Application costs will vary widely, and considerable improvement will no doubt be made on the application methods used in these studies. For the initial kill in heavily infested ditches it has been found necessary to apply the herbicides at the rate of 200 ppm uniformly throughout the ditch section when the water stage just covers the weeds. This concentration would require approximately 8 gallons of herbicide per sq. ft. of wetted cross-section per mile. Based

on an estimate of $1.25 per gallon, the material cost for an average size farm ditch of 6 sq. ft. would be approximately $60 per mile, while a lateral with 30 sq. ft. would run $300 per mile.

From these estimates it appears that herbicidal treatment will be economically feasible for initial cleanout only for the small to moderate size ditches and not for large arterial waterways. However, once the heavy growth has been cleaned and flow opened, periodic maintenance every three to six months will be considerably cheaper by using the "slug" treatment as developed for the cleaning of mosses in irrigation ditches in the western United States (4). By this method the herbicide is introduced into the flowing stream at a point of turbulence and carried downstream, contacting and killing the plants enroute. A concentration of 300 to 400 ppm for a contact period of from 30 to 40 minutes has been found to be effective against the naiad for distances of approximately 1 mile. Smaller booster shots at ½ mile intervals increase the killing distance. Thus, a larger ditch with flow of 4,500 gallons per minute could be treated with 55 gallons of herbicide at a material cost of about $75 per mile.

It is believed that aquatic weed control costs for farms in the south Florida area can be materially reduced and flow efficiencies improved by periodic application of a herbicidal material blended for boiling range, aromaticity and specific gravity to suit specific conditions as determined by individual farm requirements.

SUMMARY

The southern naiad, *Najas guadalupensis* (Spreng.) Morong., a submersed water weed commonly infesting the water control systems of south Florida, can be economically controlled in farm ditches, under the quasi-static water conditions prevalent in the region, by the underwater application of several emulsifiable oils that are obtainable from regional sources.

Low cost solvents, oils, and gasolines can be blended with a cheap grade of heavy, mixed chlorinated benzenes and suitable emulsifiers to yield potent aquatic herbicides with specific gravities that can be varied to meet different infestation and application conditions.

Compressed inactive gases, such as carbon dioxide and nitrogen, can safely and economically supply propelling power for spray applications of the low flash point herbicides.

Preliminary toxicity tests indicate that there is little danger to crop plants or animals watered from treated sources containing these herbicides at concentrations needed for aquatic weed and snail control.

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Species Sensitivity to Chemicals Tested for Herbicidal Properties[1]

JAMES W. BROWN and J. ARTHUR THRONE[2]

TO THOSE engaged in testing chemical compounds for herbicidal properties a troublesome problem is familiar, namely, what species or small group of species can best represent the reaction of many plants to a compound the potential of which is unknown.

The extreme approaches to this problem are to test all species or to test one. The first alternative is obviously not feasible even though further complicating factors such as rates, stages of plant development, environmental conditions, formulations, methods of application, criteria of response, and immediate herbicidal objectives are not considered. The second alternative has distinct limitations when considered from the standpoint of a herbicidal program of broad scope. A judicious compromise is essential in order to obtain a reasonable degree of assurance that once a compound is tested and shows little or no activity, it would also fail to indicate a possible new type of active chemical structure or to become a useful product in keeping with the objectives of the program. Most programs are concerned with gaining assurance that the methods employed for testing compounds are such that no potentially active compound will be missed in the primary screening. Thus, there is reason for increasing the sensitivity of the first test and allowing subsequent trials to be more discriminatory.

As a result of screening many compounds, information has been obtained which has been arranged to emphasize the relationship of the sensitivity of different species to many compounds. Hence, it is possible to determine which of several species can be expected to be the most responsive to untested compounds.

Test plants and abbreviations used in this study are as follows:

	Abbreviation
Black-eye peas	BEP
Black Valentine beans	BVB
Buckwheat, Japanese	Buc
Cotton, Coker #100	Cot
Cucumber, Early Fortune	Cuc
Morning-glory, Heavenly Blue	MG
Radish, Scarlet Globe	Rad
Soybean, Lincoln	Soy
Sunflower, Russian Mammoth	Sun
Barley, Wong	Bar
Corn, U. S. #13	Cor
Oats, Clinton	Oat
Rice, Collusa	Ric
Rye, Abruzzi	Rye
Wheat, Thorne	Whe

[1]Acknowledgment is made to the following persons for assistance in conducting these tests: L. W. Boyer, W. S. Coghill, J. C. George, R. H. Hamilton, T. S. Hitchcock, J. A. Kramer, A. V. Mattie, R. A. Scherff, P. V. Wells, and R. L. Zahn.

[2]Chemical Corps Biological Laboratories, Camp Detrick, Frederick, Md.

METHODS AND RESULTS

Information presented in conjunction with a paper (1) describing two tests for herbicide screening is shown here (Table 1) in order to illustrate that, in addition to the measure of reproducibility of a root test, morning-glory was indicated as the most responsive of 13 species to 2,4-dichlorophenoxyacetic acid.

Table 1. Reproducibility of a root test showing per cent inhibition of root growth of 13 species and rank of sensitivity to 1 ppm of 2,4-D acid.

Species*	Dates of tests (1952) and percentage of inhibition					Mean percentage inhibitions	Sensitivity rank
	6–3	7–14	8–22	9–15	10–27		
BEP	80	75	78	75	86	79	5
BVB	60	60	63	40	60	57	9
Buc	71	50	83	67	80	70	7
Cot	86	80	83	86	80	83	3
Cuc	71	60	62	60	60	63	8
MG	83	80	100	100	80	89	1
Sun	88	83	86	80	83	84	2
Bar	25	17	38	38	29	29	13
Cor	36	33	25	38	29	32	12
Oat	57	50	29	33	60	46	11
Ric	83	67	89	88	71	80	4
Rye	63	67	82	71	71	71	6
Whe	43	40	57	50	50	48	10
Mean	65	59	67	64	65	64	

*See text for names of abbreviations.

A greenhouse spray test (1) was employed for obtaining the information contained in Table 2. The 92 compounds tested by this means on each of 13 species had been previously screened by a root test and most of them had shown some indication of activity. In Table 2 the numbers marked with an asterisk (*) indicate how many of the 92 compounds showed activity on each species listed. The remaining numbers indicate how many compounds showed activity on both of any two of these species. For instance, Black-eye peas (Table 2A) responded to 45 compounds and Black Valentine beans responded to 51. However, only 41 compounds (intercept of BEP column and BVB line or intercept of BVB column and BEP line) were active on both of these species, or, expressed differently, Black-eye peas indicated activity for 41 compounds which were active on Black Valentine beans and, conversely, Black Valentine beans indicated activity for 41 compounds which were active on Black-eye peas. Also, 4 compounds (45*–41) were active on Black-eye peas but not active on Black Valentine beans while 10 compounds (51*–41) were active on Black Valentine beans but not active on Black-eye peas.

Further inspection of the 25–100% inhibition category (Table 2A) reveals that, of 92 compounds spray-tested, morning-glory responded to 66 (74%). Black Valentine beans and Early Fortune cucumber each responded to 51 (55%), and Black-eye peas responded to 45 (49%). It is of interest to note that of the species tested, no one species responded in a way that was fully descriptive of the

Table 2. Number of compounds, of 92 previously screened in a root test, inhibiting fresh weight of tops when sprayed on 6–9 day plants of each species at a 0.01 lb./A rate. Weights taken 2 weeks after treatment.

(A) 25–100% Inhibition

Species	BEP	BVB	Buc	Cot	Cuc	MG	Sun	Bar	Cor	Oat	Ric	Rye	Whe
BEP	45*	41	23	33	32	41	24	6	3	8	4	14	3
BVB	41	51*	23	33	37	43	24	8	8	6	6	14	3
Buc	23	23	35*	25	25	31	13	7	7	9	9	11	2
Cot	33	33	25	39*	29	35	21	5	4	7	6	9	2
Cuc	32	37	25	29	51*	42	27	9	9	9	9	14	2
MG	41	43	31	35	42	66*	26	11	11	13	9	16	4
Sun	24	24	13	21	27	26	32*	4	5	6	4	8	2
Bar	6	8	7	5	9	11	4	13*	4	4	2	3	1
Cor	3	8	7	4	9	11	5	4	21*	5	3	2	1
Oat	8	6	9	7	9	13	6	4	5	19*	3	4	1
Ric	4	6	9	6	9	9	4	2	3	3	13*	5	0
Rye	14	14	11	9	14	16	8	3	2	4	5	21*	2
Whe	3	3	2	2	2	4	2	1	1	1	0	2	5*

(B) 50–100% Inhibition

BEP	29*	21	7	15	11	23	5	0	0	0	0	0	0
BVB	21	32*	7	13	15	21	5	0	0	0	0	0	0
Buc	7	7	10*	7	5	8	2	0	0	0	0	0	0
Cot	15	13	7	21*	10	18	5	0	0	0	0	0	0
Cuc	11	15	5	10	20*	17	5	0	0	0	0	0	0
MG	23	21	8	18	17	39*	6	0	0	0	0	0	0
Sun	5	5	2	5	5	6	6*	0	0	0	0	0	0
Bar	0	0	0	0	0	0	0	0*	0	0	0	0	0
Cor	0	0	0	0	0	0	0	0	0*	0	0	0	0
Oat	0	0	0	0	0	0	0	0	0	1*	0	0	0
Ric	0	0	0	0	0	0	0	0	0	0	0*	0	0
Rye	0	0	0	0	0	0	0	0	0	0	0	0*	0
Whe	0	0	0	0	0	0	0	0	0	0	0	0	0*

*Number of compounds affecting a single species (other entries represent number of compounds active on each of 2 species as indicated).

sensitivity of any other species. Where the beans and cucumber indicated sensitivity to an equal number of compounds (51), these compounds were not identical in that only 37 of them were active on both of these species while 28 compounds were, in this case, active only on one of these two species (14 active only on beans, and 14 active only on cucumber). Morning-glory, however, not only responded to a greater number of the compounds but also responded to a higher proportion of those compounds which were active on any other single species tested. Morning-glory responded to an average of 86% of the compounds which were active on the six other broadleaved species and to an average of 72% for the six cereal species (Table 3). For the broadleaves and cereals combined, morning-glory responded to an average of 79% of the compounds effective on them, or about 4 compounds out of 5. Black Valentine beans and cucumber were about equal in sensitivity but were somewhat less responsive than was morning-glory. Cotton was still less responsive.

The reduction of the numbers of compounds in Table 2B is to be expected due to the greater effect required for inclusion in this section, nevertheless, more compounds indicated activity on morning-glory than on any of the other species. This reduction is somewhat extreme for the cereals in that only 1 of the 92 compounds

Table 3. The responsiveness of morning-glory, Black Valentine beans, cucumber, and cotton to compounds which were active on other species (Table 2A). Response is expressed as percentage of compounds which were active on each species.

Species*	MG	BVB	Cuc	Cot
	Broadleaf Species			
BEP	91	91	71	73
BVB	84	—	73	65
Buc	89	66	71	71
Cot	90	85	74	—
Cuc	82	73	—	57
MG	—	65	64	53
Sun	81	75	84	68
Broadleaf average	86	76	73	64
	Cereal Species			
Bar	85	62	69	38
Cor	52	38	43	19
Oat	68	32	47	37
Ric	69	46	69	46
Rye	76	67	67	43
Whe	80	60	40	40
Cereal average	72	51	56	37
Overall average	79	63	64	51

*See text for names of abbreviations.

showed 50% or more inhibition on any of the 6 cereal species. It should be borne in mind that the rate of application (0.1 lb/A) being low would tend to exclude compounds known to affect cereals at higher application rates.

It appears from the data (Table 2) that no one cereal species is as good an indicator of compounds active on other cereals as is any of several broadleaved species, such as morning-glory, cucumber, or Black Valentine beans.

The 92 compounds tested included the following chemical groupings:

Compound group	Number of compounds	Percentage of total
Phenoxy	53	58
Benzoic	3	3
Carbamate	12	13
Urea	20	22
Other	4	4
Total	92	100

For compounds which had not been previously tested, a greenhouse spray test was employed which differed from the spray test already described (1) in that the rates were 0.1 and 1 lb/A and the number of species reduced from 13 to 6. The results of testing 484 compounds on each of the 6 species are shown in Table 4. In each

category morning-glory responded to the greatest number of compounds and with only 6 exceptions responded to an equal number or more compounds which also affected other species. These exceptions were: Black Valentine beans (Table 4A), soybeans (Table 4B), and radish (Table 4D) each indicating activity for two more compounds which also affected oats; Black Valentine beans and soybeans (Table 4D) each indicating activity for one more compound which also affected oats; and Black Valentine beans indicating activity for one more compound which also affected rice (Table 4D).

Table 4. Number of compounds, of 484 not previously tested, inhibiting fresh weight of tops when sprayed on 6–9 day plants of each species at 0.1 and 1.0 lb/A rates. Weights taken 2 weeks after treatment.

	BVB	Soy	MG	Rad	Oat	Ric
(A) 25–100% Inhibition—0.1 lb/A						
BVB	65*	35	41	26	8	16
Soy	35	84*	41	40	5	15
MG	41	41	124*	45	6	18
Rad	26	40	45	95*	5	12
Oat	8	5	6	5	15*	4
Ric	16	15	18	12	4	50*
(B) 25–100% Inhibition—1 lb/A						
BVB	170*	112	133	122	45	83
Soy	112	194*	146	146	52	30
MG	133	146	237*	164	50	109
Rad	122	146	164	230*	46	99
Oat	45	52	50	46	65*	37
Ric	83	30	109	99	37	152*
(C) 50–100% Inhibition—0.1 lb/A						
BVB	21*	12	15	9	0	2
Soy	12	21*	16	12	0	2
MG	15	16	36*	20	0	2
Rad	9	12	20	24*	0	2
Oat	0	0	0	0	0*	0
Ric	2	2	2	2	0	3*
(D) 50–100% Inhibition—1 lb/A						
BVB	71*	39	49	42	6	13
Soy	39	59*	43	39	6	12
MG	49	43	90*	52	5	12
Rad	42	39	52	75*	7	12
Oat	6	6	5	7	7*	3
Ric	13	12	12	12	3	18*

*Number of compounds affecting a single species (other entries represent number of compounds active on each of 2 species as indicated).

DISCUSSION

It appears that from the data presented here it would be inadvisable to rely entirely on a single species as a test plant in screening. At the same time the suggestion is obvious that until more is learned of the responses of different species it would probably be wise to include morning-glory as a test species where it is desirable to minimize the number of plant species to be used in testing. If the screening objectives are broad, the foregoing applies. On the other hand, if the objectives are limited to the eradication of a resistant species, testing compounds on morning-glory might not necessarily offer the best means of attaining this end. The results of such tests

would, however, tend to indicate compounds or compound structures which might lead eventually to the development of a herbicide having the desired qualities. Testing the resistant species involved would generally indicate whether or not a given compound could be used, but would not necessarily indicate compounds analogues of which might prove active.

SUMMARY

In two different tests morning-glory was the most responsive of 15 species and responded to a greater proportion of compounds which were active on other species, whether or not the compounds employed had been previously screened for activity. No species, of those tested, could be used to predict accurately the response of any other species.

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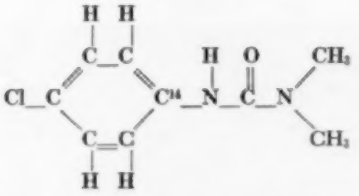
Translocation of 3-(*p*-Chlorophenyl)-1, 1-Dimethylurea in Plants**†

J. R. HAUN and J. H. PETERSON

SINCE it was first discovered by Bucha and Todd (1), that 3-(*p*-chlorophenyl)-1, 1-dimethylurea would kill most plants if applied at dosages of 20 pounds and above per acre there has been much speculation as to whether it is translocated in plants. Observations from early field trials indicating that soil treatments with this compound were more effective than foliar applications led to the assumption that entrance of the herbicide into plants was primarily through the roots (4). Loustalot (3) demonstrated positively, however, that this substituted urea is also absorbed through the leaves and stems. Recent investigations at this laboratory, contrasting essentially equal applications on foliage and roots of several species, have also indicated that appreciable injury is caused by foliar absorption of the compound.

In order to determine whether this compound moved in the plant, C^{14} ring-labeled 3-(*p*-chlorophenyl)-1, 1-dimethylurea (Fig. 1) was synthesized (2)[1] and used in solution culture studies. Because of the

FIG. 1. Position of C^{14} in the 3-(*p*-chlorophenyl)-1, 1-dimethylurea used in these experiments.

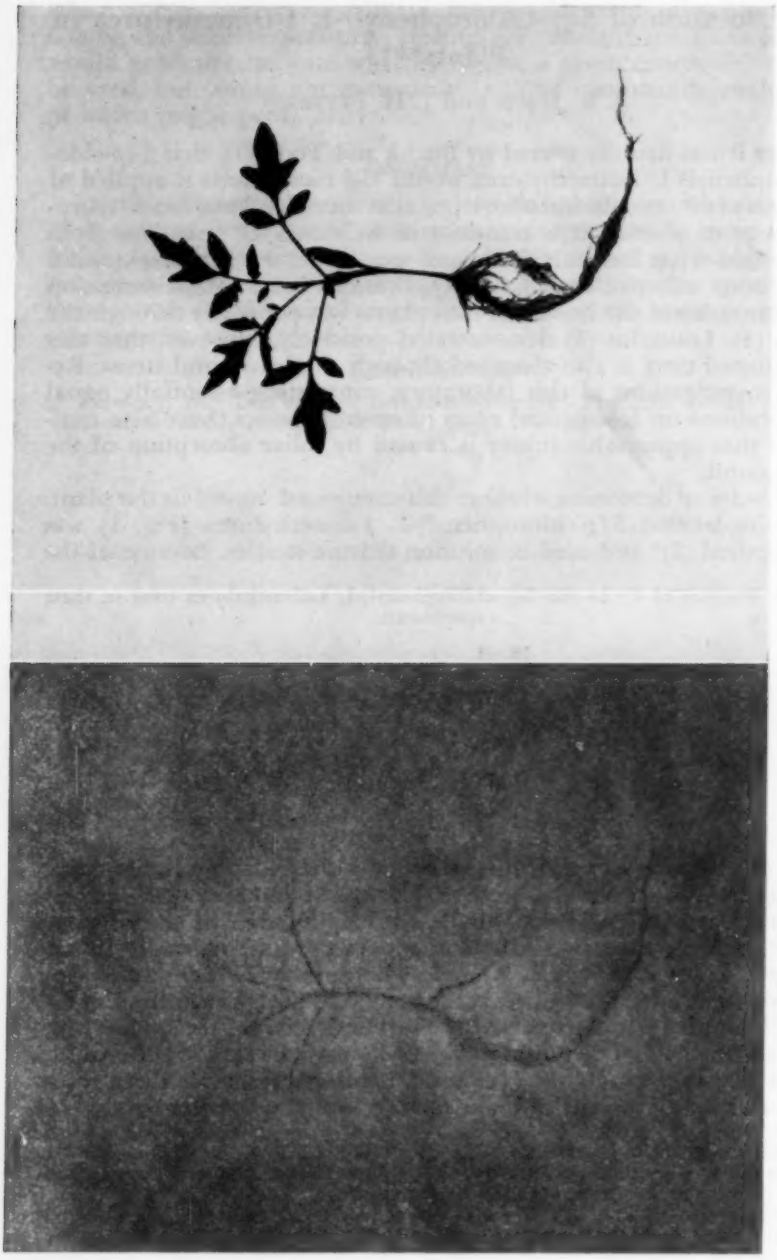


ease of culturing in nutrient solution and their adaptability to tracer techniques, tomato plants were used for these experiments. The concentrations of 3-(*p*-chlorophenyl)-1, 1-dimethylurea in the nutrient solution were such that kill of the plants would normally be obtained in about ten days. Tomato plants thirty-five days old were placed in a nutrient solution containing 0.25 parts per million of C^{14} ring-labeled 3-(*p*-chlorophenyl)-1, 1-dimethylurea. At two-hour intervals for the first 12 hours and at 24-hour intervals thereafter up to six days, single plants were removed, the roots washed in three rinses of water, and each entire plant pressed between blotting paper. All

[1]Acknowledgment is made to N. E. Searle and H. E. Cupery, Chemical Department, who synthesized the ring-labeled 3-(*p*-chlorophenyl)-1, 1-dimethylurea used in these experiments, for their help and advice.

**Contribution from the Grasselli Chemicals Department and the Chemical Department (No. 358), Experimental Station, E. I. du Pont de Nemours & Co., Wilmington, Delaware.

†Presented as an invitational paper at the First National Weed Control Conference, Kansas City, Mo., Dec. 8, 1953.

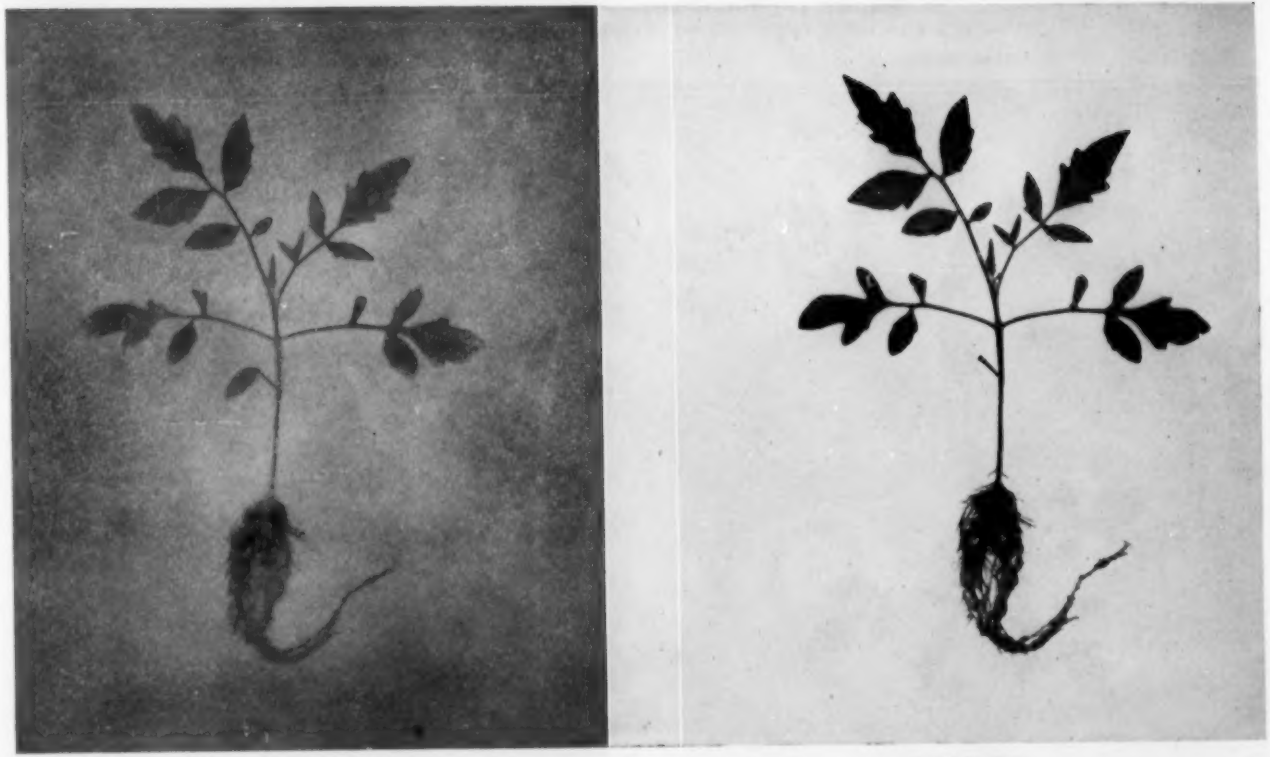


SILHOUETTE

RADIOAUTOGRAM

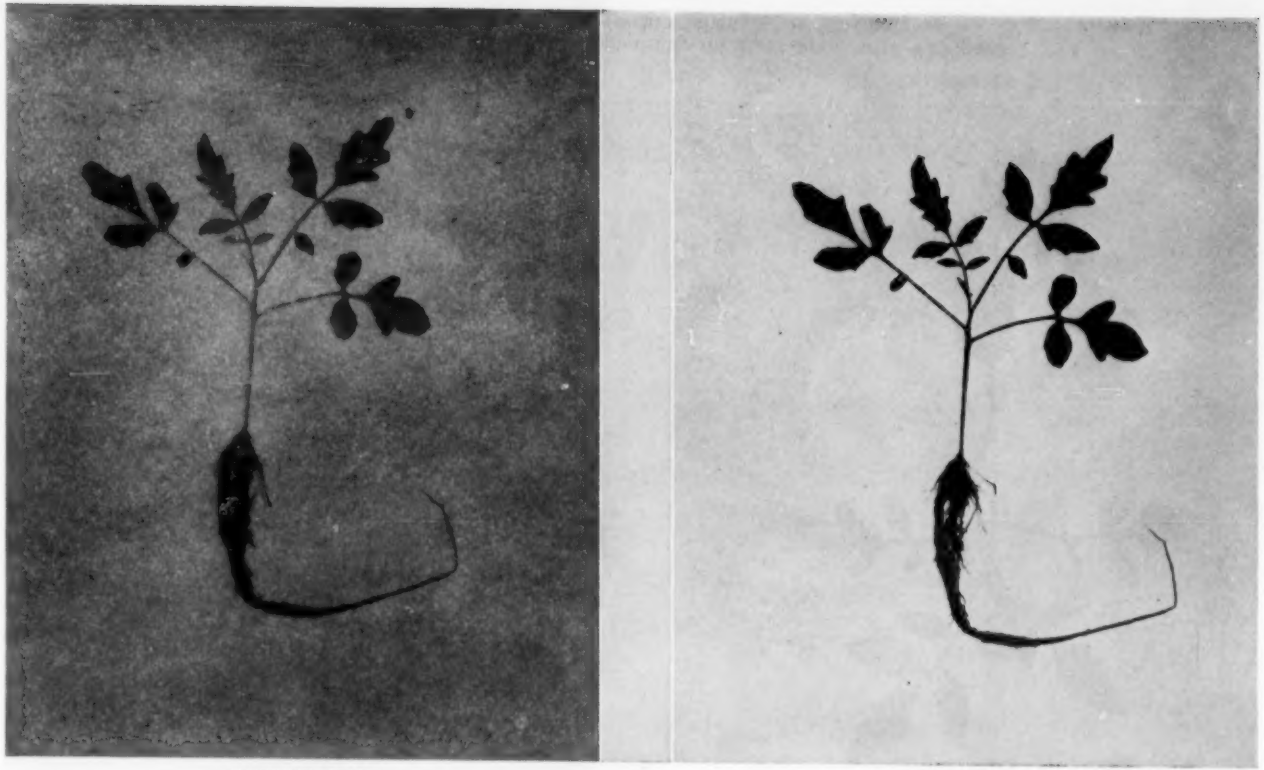
FIG. 2. Tomato plant treated hydroponically for two hours with 0.25 parts per million of ring-labeled 3-(*p*-chlorophenyl)-1, 1-dimethylurea.

FIG. 2. Tomato plant treated hydroponically for two hours with 0.25 parts per million of ring-labeled 3-(*p*-chlorophenyl)-1, 1-dimethylurea.



RADIOAUTOGRAM SILHOUETTE

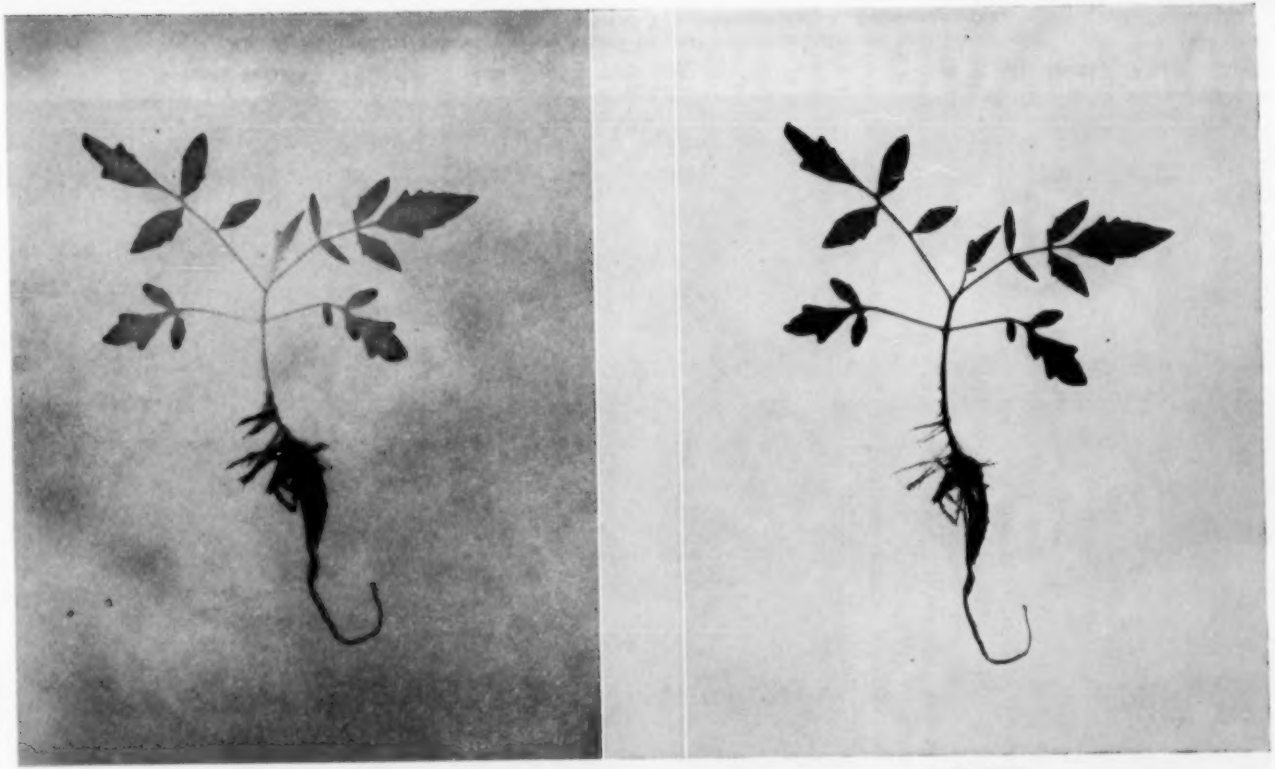
FIG. 3. Tomato plant treated hydroponically for eight hours with 0.25 parts per million of ring-labeled 3-(*p*-chlorophenyl)-1, 1-dimethylurea.



RADIOAUTOGRAM SILHOUETTE

FIG. 4. Tomato plant treated hydroponically for forty-eight hours with 0.25 parts per million of ring-labeled 3-(*p*-chlorophenyl)-1, 1-dimethylurea.

per million of ring-labeled 3-(*p*-chlorophenyl)-1, 1-dimethylurea.



RADIOAUTOGRAM SILHOUETTE

FIG. 5. Tomato plant treated hydroponically for six days with 0.25 parts per million of ring-labeled 3-(*p*-chlorophenyl)-1, 1-dimethylurea.

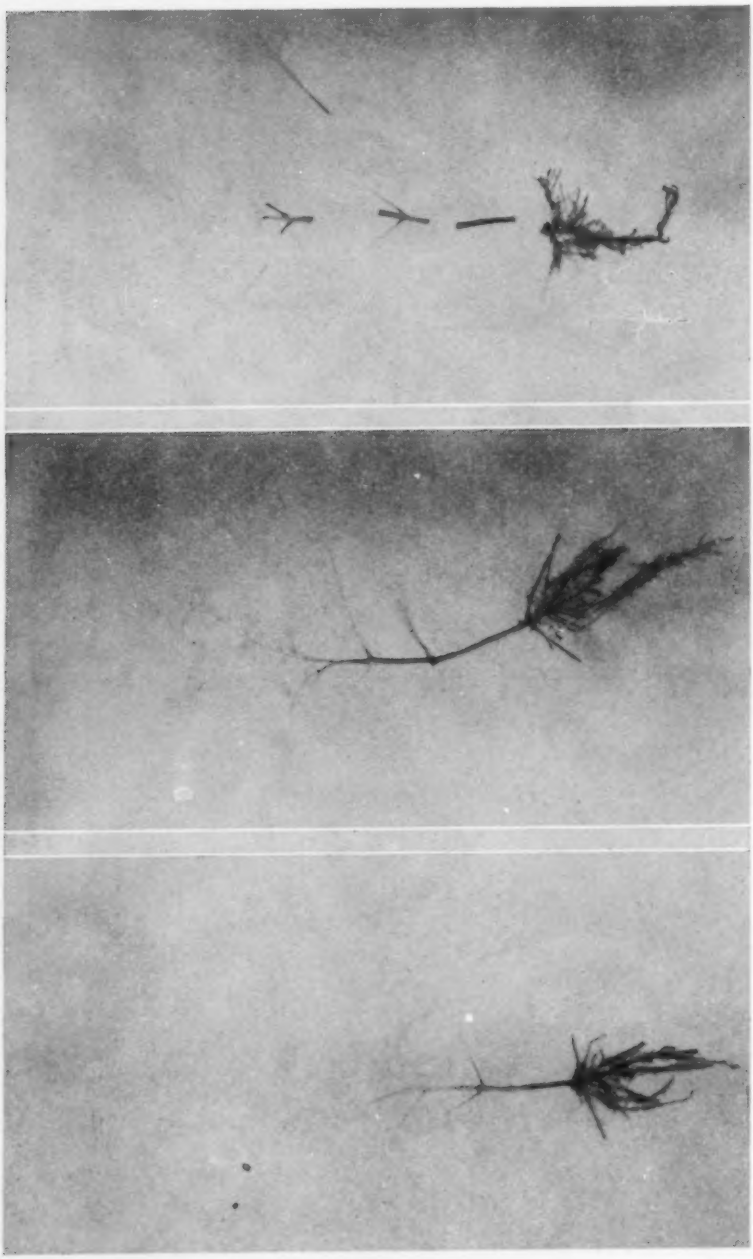


FIG. 6. Radioautograms of tomato plants treated hydroponically for two hours with 0.25 parts per million of ring-labeled 3-(*p*-chlorophenyl)-1, 1-dimethylurea.

plants were pressed with the foliage on one side of the main axis placed with the adaxial surface upward and foliage on the opposite side with abaxial surface upward. Pressed plants were kept in a warm room and the blotting paper changed frequently to insure rapid drying. After air-drying, specimens were placed in contact with X-ray film for a period of 22 days. The extent of C^{14} movement in the plants is evident in the resulting radioautograms (Fig. 2–5).

To determine whether diffusion or translocation of this compound might have taken place during the drying period, four plants were treated with 0.25 ppm ring-labeled 3-(*p*-chlorophenyl)-1, 1-dimethylurea in the nutrient solution and harvested at the earliest sampling time (2 hours) and prepared for radioautographing by two different methods. Two plants were frozen and two were sectioned into pieces of approximately one inch in length immediately at time of harvest. Afterward all four plants were dried in the manner previously described. Radioautograms of these plants (Fig. 6) confirmed the rate of upward movement of the chemical found in radioautograms of plants which were dried in the routine manner.

It is of interest to note that an appreciable amount of C^{14} was present throughout the aerial portions after a two hour exposure to treatment. The concentration of C^{14} in the roots of the tomato plant increased very gradually throughout the period of treatment whereas the concentration in the aerial parts increased quite rapidly. These distribution effects were further defined by more precise quantitative measurements of C^{14}.

Tomato plants growing in nutrient solutions containing 2 ppm ring-labeled 3-(*p*-chlorophenyl)-1, 1-dimethylurea were sampled at the same 12 intervals of time after treatment and radioassayed for C^{14} by the windowless counter method. Older plants were used in this experiment to provide sufficient bulk for the analysis of various plant parts. The use of older plants also necessitated the use of higher concentrations of the chemical for similar effects. The results of C^{14} radioassays in plant parts are given in Table 1 and the 3-(*p*-chloro-

Table 1. 3-(p-chlorophenyl)-1, 1-dimethylurea content of tomato plants* treated hydroponically with 2.0 ppm C^{14} ring-labeled 3-(*p*-chlorophenyl)-1, 1-dimethylurea as calculated from radioassays for C^{14}.

Hours in 2 ppm CMU solution	3-(*p*-chlorophenyl)-1, 1-dimethylurea (ppm) based on dry weight		
	Roots	Lower aerial portions†	Upper aerial portions‡
2	31	11	7
4	46	33	24
6	38	29	28
8	41	25	29
10	49	25	22
12	41	38	30
24	47	81	37
48	53	126	173
72	70	137	158
96	50	159	250
120	81	240	260
144	56	226	268

*Forty-one days old when placed in 3-(*p*-chlorophenyl)-1, 1-dimethylurea solutions.
†Lower stem including primary leaves and first true leaf.
‡The remaining portion of the plant after roots and lower portions were removed.

phenyl)-1, 1-dimethylurea content of the dry plant material is presented graphically in Fig. 7.

Again, rapid upward translocation was noted. Seven parts per million of 3-(*p*-chlorophenyl)-1, 1-dimethylurea as calculated by radioassay of C^{14} were accounted for in the upper portion of a tomato plant with roots exposed for two hours in a nutrient solution containing 2 parts per million of the chemical. The C^{14} content of samples taken after 10 and 12 hours exposure did not increase appreciably over previous samples. These samples were taken at night and reflect the variations which might be expected from hourly fluc-

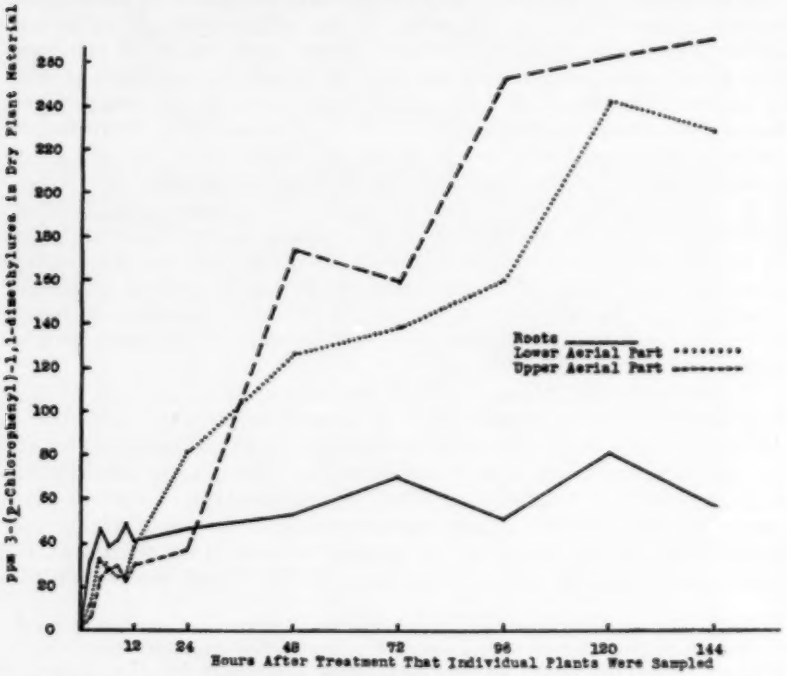


FIG. 7. ppm. 3-(*p*-chlorophenyl)-1, 1-dimethylurea in dry plant material as calculated from radioassays for C^{14} in tomato plants treated hydroponically with 2.0 ppm C^{14}-ring-labeled 3-(*p*-chlorophenyl)-1, 1-dimethylurea (plants were 41 days old when placed in treatment).

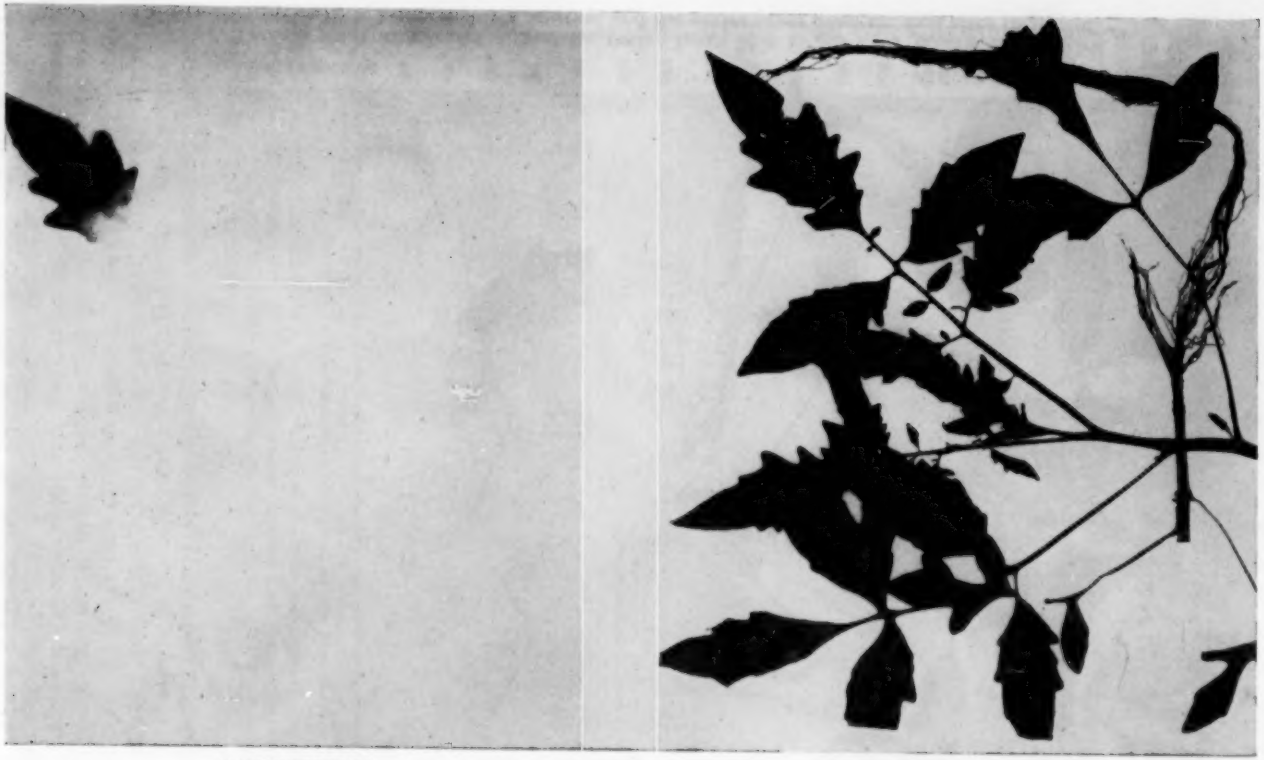
tuations in translocation. At approximately 116 hours of exposure the plants were beginning to show visual symptoms of injury.

It is a common observation that plants treated with 3-(*p*-chlorophenyl)-1, 1-dimethylurea show no marked response for several days. Greenhouse observations of treated plants, however, show that growth stops relatively soon after treatment but chlorosis and dieback of leaf tips may not be apparent for 3–10 days. Studies are in progress on the physiological action of 3-(*p*-chlorophenyl)-1, 1-dimethylurea during the period of absorption before injury of specific tissues appears.

SILHOUETTE

RADIOAUTOGRAM

FIG. 8. Tomato plant with leaflet dipped for twelve hours in a 10 parts per million ring-labeled 3-(*p*-chlorophenyl)-1, 1-dimethylurea solution and the entire plant dried six days after treatment.



RADIOAUTOGRAM SILHOUETTE

FIG. 9. Tomato plant treated with 0.1 mg. 3-(*p*-chlorophenyl)-1, 1-dimethylurea within a lanolin ring on one leaflet and the entire plant dried six days after treatment.

To determine the extent of downward translocation resulting from foliage treatments, leaf tips of tomato plants were submerged in ring-labeled 3-(*p*-chlorophenyl)-1, 1-dimethylurea solutions (10 ppm) for a period of 24 hours. Radioautograms of these plants showed little C^{14} below the area of application (Fig. 8). In a second experiment, small quantities of 3-(*p*-chlorophenyl)-1, 1-dimethylurea solutions were applied in lanolin rings over the midrib of tomato leaflets. The portion of the leaflet distal to the treated circle showed typical 3-(*p*-chlorophenyl)-1, 1-dimethylurea toxicity symptoms whereas no visible symptoms were apparent below the treated area. Radioautograms (Fig. 9) confirm that there was very little movement of C^{14} downward in the treated leaves. This suggests that movement of 3-(*p*-chlorophenyl)-1, 1-dimethylurea in plants occurs mainly in the xylem.

Similar experiments were conducted using monocotyledonous plants such as corn and Johnson grass seedlings. The data obtained indicate the same general trends as with tomatoes, namely that translocation upward was very rapid but that downward translocation was *nil*.

It will be noted from these data that the amounts of 3-(*p*-chlorophenyl)-1, 1-dimethylurea in plants can be relatively high when the plants are grown in solution culture in the presence of a relatively high concentration of the compound and when the samples are taken immediately after treatment. It is apparent, however, from other work that such amounts would not be found in crops which have been treated with pre-emergence applications of the herbicide. We have conducted a large number of analyses on crops which have been treated with pre-emergence applications and in all of the crop studies, which include such crops as corn, onions, asparagus, pineapple, sugar cane, and cotton, the average amount of 3-(*p*-chlorophenyl)-1, 1-dimethylurea in any portion of the plant has been less than .01 ppm, which approaches the limit of sensitivity of the method of analysis. Data on crop analyses will be published in due course.

While these investigations demonstrate the pattern of movement of C^{14} in plants treated with radioactive 3-(*p*-chlorophenyl)-1, 1-dimethylurea, it is recognized that they do not establish the translocation of the intact molecule. Experiments to clarify this point are being conducted.

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A Statewide Extension Program in Weed Control*

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AS IN many other states, weed control is a serious problem in North Dakota. To meet the situation a statewide control program has been developed over the years by the Extension Service with the Extension Service Agronomist in charge, As the weeds were still gaining ground special emphasis was placed in 1953 and 1954 on a statewide program for more effective weed control.

The results being obtained in this program represent the combined activity of the entire Extension organization and the ideas of many persons and agencies working together to reduce the weed problem. This program is far from perfect and a lot of work is still to be done. A report of how it was organized and what is being accomplished may provide some ideas that will be helpful in other states.

The importance of weed competition in our small grain crops was impressed on me by an observation made in the fall of 1952. In Spiritwood, a small town in the east central part of North Dakota, a large pile of weed seed screenings on the ground near the grain elevator was observed. A few questions to the elevator manager brought out the facts that the pile included 2,000 tons of weed screenings which had been cleaned out of grain purchased by the elevator that fall and other lots of screenings purchased in the area. A few calculations concerning the moisture and fertility required to produce these common weeds indicated that this huge pile of weed screenings represented a loss of approximately 70,000 bushels of wheat. As this pile of screenings represented only a small percentage of the total weeds growing in competition with grain crops in North Dakota during that season, the importance of more effective weed control becomes apparent.

ORGANIZING THE PROGRAM

The first step in organizing the 1953 weed control program was a series of district conferences with county extension agents held in November 1952. At these conferences plans were worked out with the Extension Agronomist as to ideas to be included in the program and what publicity, information and bulletins would be needed. Plans were also agreed upon for a survey to measure accomplishments at the end of the year.

In the 1953 program main emphasis was placed on radio and newspaper publicity on the importance of weed control, sprayer calibration for more effective control, farm demonstrations, demon-

*Invitation paper presented at the First National Weed Control Conference, Kansas City, Mo., Dec. 9, 1953.

strations of chemical control of leafy spurge and cultural weed control demonstrations with cooperating farmers. At district conferences with county extension agents in May and September, plans and progress were discussed with the Extension Agronomist.

ASSISTANCE AND INFORMATION PROVIDED

The Extension Agronomist coordinated the ideas and plans suggested by county extension agents and farmers into a statewide weed control program which was sent to all agents. Throughout the year information, training and guidance for the program was provided as follows:

1. With the cooperation of Experiment Station personnel six Extension Service circulars and bulletins were published on chemical weed control, cultural practices, prohibited noxious weeds, the mixing of chemicals and sprayer calibration.

2. In May district training schools were conducted for county agents with the cooperation of the Extension Agricultural Engineer on farm sprayer adjustment and calibration. Procedure and equipment were demonstrated and a plan for community demonstrations by county agents was presented.

3. Plans were sent out in May to county agents for farmer demonstrations of selective weed control in growing crops. Check strips were to be left untreated so that yield comparisons could be obtained in the fall. A simple procedure for obtaining yield results by combine was prepared with the cooperation of the Extension Agricultural Engineer and was sent to county agents before harvest. A special effort was made to follow through on these demonstrations and get yield comparisons to prove effectiveness.

4. Leafy spurge is the most wide-spread noxious weed in North Dakota. It can be found in every county in the state, therefor chemical control demonstrations were organized. Chemicals, provided free of charge by chemical companies, were packaged and delivered to county agents with instructions for applying seven treatments on square rod plots to demonstrate the most effective chemical control.

5. As no satisfactory chemical control was available for wild oats which is a serious weed in North Dakota, suggestions were provided to county agents for working out long-time cultural demonstrations on individual farms. Similar control programs were started for control of noxious weeds such as perennial sow thistle, field bindweed and leafy spurge.

6. Assistance was given county agents in recommendations and procedures for organizing roadside spraying programs with county commissioners and township officers.

7. Visual aids for use at county meetings were provided at cost to county agents. These included such things as weed seeds, weed mounts, colored slides of noxious weeds, slides showing importance of weed control and crops judging aids for 4-H, FFA and adult groups.

8. A series of seven weekly publicity stories on weeds was prepared and sent out in May and June to county agents for local adaptation and use in news stories and radio programs. Agents provided additional publicity of progress and result stories.

ACCOMPLISHMENTS MEASURED

At district conferences with county extension agents in September the Extension Agronomist worked out plans for a statewide survey to measure the accomplishments of the year's program. A questionnaire was prepared and sent to every agent. On the basis of their records and observations county agents reported results of their county programs. The summary indicated the following results obtained in the 1953 weed control program in North Dakota.

1. Extension circulars:
   - Circulars and bulletins published 7
   - Total bulletins distributed 37,251
2. Sprayer calibration demonstrations:
   - Demonstrations conducted by agents 66
   - Total attendance 2,535
3. Selective weed control demonstrations:
   - Total demonstrations 231

   These included selective control in growing grain crops with 2,4-D, MCP, TCA or a combination of these chemicals.
   - Farms on which yield results were obtained 10
   - Increased yield average of five trials on flax..... .....4.4 bushels per acre
   - Increased yield average of three trials on barley..... .....4.0 bushels per acre

   While these yield results do not represent a large enough cross section of the demonstrations, they do indicate what happened in these instances. An effort will be made in the 1954 program to get a larger number of yield results.

Acreage treated in 1953 with 2,4-D, MCP, TCA, or combinations:

Small Grain	2,124,330 acres
Flax	481,095
Corn	8,655
Fallow	65,805
Pasture	27,840
Other	3,831
Total	2,711,556

4. Leafy spurge demonstrations:
   - Number of demonstrations—54 in 40 counties
5. Noxious weed control:
   - Farmers treating noxious weed patches 7,665
   - Farmers controlling noxious weeds in fields ... 11,823
   - Farmers assisted in starting long-time weed control programs 1,311

6. Roadside spraying:
   - Counties with organized programs 13
   - Counties with township programs 9
   - Total townships cooperating 129
   - Miles of roadside treated 3,675
   - Noxious weed patches treated on roadsides 6,485

   Total soil sterilants applied in treating noxious weed patches:
   - Sodium chlorate .....151,926 lbs.
   - Borate-chlorate ..... 41,886 lbs.
   - Borate ..... 9,600 lbs.
   - CMU ..... 345 lbs.
   - Other ..... 7,400 lbs.

7. Visual aids prepared:
   - Sets of 15 colored slides of noxious and common weeds 78
   - Sets of 20 weed mounts 21
   - Partial sets of weed mounts 16
   - Weed seed kits of 40 common weeds 34
   - Special 4-H Club circular on weed seed identification

8. Publicity:
   - County news stories 438
   - County radio programs 150
   - County weed control meetings 282
   - Total attendance 16,998

Evaluation of Several Chemicals for Weed Control in Strawberry Fields[1]

D. H. Scott, W. C. Shaw, and R. U. Ruppenthal[2]

The control of weeds in strawberries is one of the most essential factors in strawberry production. Strawberry plants are easily overgrown by tall, rapidly growing weeds and, in a few weeks, they may be severely damaged. Hand hoeing to control weeds in strawberry plantings is a very expensive operation varying from $100 to $300 an acre, or even more depending upon the weed infestation. Growers have used various means of reducing weed competition, including the use of geese, the use of virgin land, lands relatively free of weeds, and fall planting for spring fruiting. In recent years, investigations have been conducted on the use of chemicals for weed control in strawberries.

Herbicides offer possibilities for weed control in strawberries depending upon the effectiveness of the chemicals and the tolerance of strawberry plants. Some herbicides, such as the dinitro compounds, kill by direct contact while others are systemic in action. Several chemicals known to have residual herbicidal properties are effective over a long period when applied to the soil. These compounds are of value in killing weed seedlings before emergence from the soil. Therefore, it appeared that these compounds might be useful as pre-planting treatments for weed control in strawberries.

In this investigation, weed control in strawberries was considered as a 3-phase problem: (1) The control of early-germinating weeds by preplanting treatments, (2) the control of summer annuals by post-planting treatments, and (3) the control of winter annual weeds by applying herbicides in late fall or during the winter while strawberry plants were dormant.

Review of Literature

Extensive studies on the use of 2,4–D (2,4–dichlorophenoxyacetic acid) for weed control in strawberries have been conducted (1, 2, 3, 5, 8, 11, 16, 18). Results indicated that 2,4–D could be used with little or no reduction in the yield of strawberry plants provided it was not applied at the time of fruit-bud formation or during the spring of the fruiting season. However, growers have been reluctant to use 2,4–D because the epinasty produced on the new leaves and runners appeared to cause severe injury. In addition 2,4–D is difficult to use safely when susceptible crops are adjacent to strawberry fields. Another limitation of the chemical is its lack of effectiveness

[1]Cooperative studies between the Horticultural and Field Crop Research Branches, Agricultural Research Service, U. S. Department of Agriculture, and the Department of Horticulture, University of Maryland.

[2]Geneticist and agronomist, respectively, Horticultural and Field Crop Research Branches, U. S. Department of Agriculture, and Research Assistant, University of Maryland.

against grasses, which are among the most serious weed pests in strawberry plantings.

Gilbert and Wolf (8) observed that SES (sodium 2,4–dichlorophenoxyethyl sulfate) caused no epinasty of strawberry plants at rates of 3 and 6 pounds per acre and that very good control of both broadleaf weeds and grasses was obtained for 6 weeks. Other studies (2, 4, 7, 9, 10, 13, 15) were in agreement with those of Gilbert and Wolf. Data obtained by Denisen (7) showed that hand labor was reduced 76 to 81 percent by 2 applications. Hemphill (10) stated that the material could be used safely during fruit-bud formation.

The use of chemicals as pre-planting treatments for weed control in strawberries was investigated by Roberts and Hemphill (18) and Bailey (2). Under Missouri conditions, 2,4–D and SES were satisfactory as pre-planting chemicals, but dichloral urea, endothal and maleic hydrazide failed to give adequate control of weeds. Bailey (2) found that 3 pounds per acre of DNBP (alkanolamine salt of dinitro ortho secondary butyl phenol) gave good control of broadleaved weeds, but did not control the grasses.

The control of weeds in fall and winter is a problem wherever chickweed *(Stellaria media)* is present. The control of chickweed and other winter weeds is an acute problem from Maryland to Missouri and southward. Danielson and Hofmaster (5) indicated that the dinitro compounds effectively controlled several winter annual weeds without injury to strawberries when applied as dormant sprays at rates of 1 to 2 pounds per acre of active ingredient. They also indicated that oil soluble dinitro compounds may seriously damage strawberry plants that are not dormant. Klingman and Morrow (14) applied chemicals for winter weed control in late November and in mid-March to Massey strawberries in North Carolina. DNBP (alkanolamine salt of dinitro ortho secondary butylphenol) at 3 pounds per acre in November gave satisfactory weed control with little or no injury to the strawberry plants. CIPC (isopropyl N–(3–chlorophenyl) carbamate) applied in March gave good weed control but was very injurious to strawberry plants. Rahn and Hitz (17) compared 3 chemicals for control of chickweed. Their most effective compound was ammonium dinitro-ortho-sec-butylphenate applied in January and March at 1 pound per acre of active ingredient.

CIPC was very effective for controlling grasses (19) and Danielson and France (6) used it successfully in strawberry plantings.

Hitz *et al* (12) used activated charcoal as a protectant spray on strawberry plants to reduce injury from CMU.

MATERIALS AND METHODS

The studies reported herein deal with experiments conducted on field plots of strawberries to determine the tolerance of strawberry plants to certain herbicides and the practical effectiveness of the chemicals in controlling weeds. The control of weeds in strawberries involves both summer and winter annual species. Summer weed

control was investigated by use of pre-planting and post-planting treatments.

The pre-planting treatments involved the application of herbicides in early spring to the surface of the soil of freshly prepared land about April 1 before the strawberry plants were set. In all cases plants were set 10 days to 2 weeks after the pre-planting sprays were applied. Chemicals used were DNBP (alkanolamine salt of dinitro ortho secondary butylphenol), MCP (amine salt of 2–methyl-4–chlorophenoxyacetic acid), CIPC [isopropyl N-(3–chlorophenyl) carbamate], CMU [3 (p–chlorophenyl)-1, 1–dimethylurea], Sesin (2, 4–dichlorophenoxyethyl benzoate), an amine salt of 2,4–D and SES (sodium 2,4–dichlorophenoxyethyl sulfate).

The post-planting treatments involved the application of SES, 2,4–D, MCP, DNBP, CIPC, Sesin, and CMU after the plants were set but prior to weed emergence. Rates of application are indicated in the tables. All chemicals were applied on an acid equivalent or active ingredient basis per acre. The chemicals were applied in 10 to 20 gallons of water per acre.

The winter weed control treatments included the application of SES, CIPC and DNBP at various rates per acre at different times to relatively dormant plants of the Tennessee Beauty variety of strawberry. The chemicals were applied in 40 gallons of water per acre. Investigations were conducted at Beltsville, Md., on a Codorus loam and near Salisbury, Md. on an Elkton light clay loam and Norfolk loamy sand.

At Beltsville the plots usually consisted of 2 rows 3½ feet apart, each 12 to 24 feet long with plants spaced 2 feet apart in the row. Four replications in randomized blocks were used for all treatments except in 1951 when 3 replications were used. Virus-free plants of Tennessee Beauty, Tennessee Shipper, or US–4194 were planted in the plots with a minimum disturbance of the soil. Chemicals were applied with a specially designed sprayer for small plot work (Fig. 1).

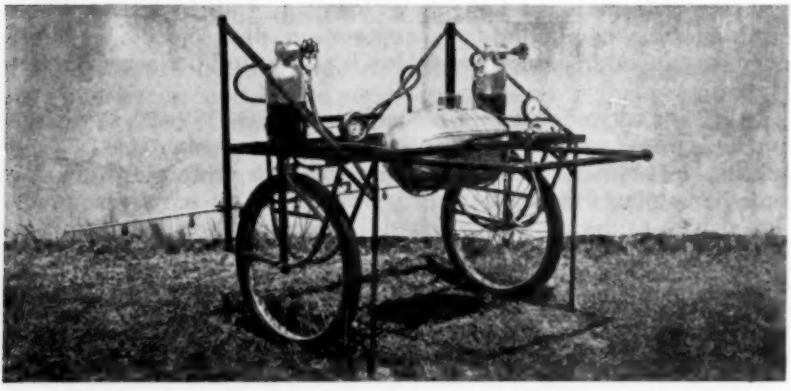

FIG. 1. Sprayer used for applying herbicides on small plots, Beltsville, Md.

Near Salisbury two commercial fields were used.[3] The plots consisted of four rows 3½ feet apart each 200 or 300 feet long with plants set about 15 to 20 inches apart in the row with a planting machine. Chemicals were applied with a tractor-drawn weed sprayer calibrated just prior to its use. Applications were made when wind movement was low, frequently near sundown. Tennessee Beauty and Blakemore plants, substantially free of virus, were grown in the fields. Records were taken from the 2 center rows of each plot near the middle of the rows.

Plant stand and runner counts were used in most cases to determine the response of strawberry plants to the different herbicides. Yield records were obtained when possible. Weed control was based on a rating system of 0 to 100 per cent, with 100 being complete control of weeds.

The principal summer weeds were crabgrass *(Digitaria sanguinalis,)* pigweed *(Amaranthus retroflexus),* Indian chickweed *(Mollugo verticillata),* and lambsquarter *(Chenopodium album).* The winter weed population consisted of chickweed *(Stellaria media)* but a light infestation of winter cress *(Barbarea vulgaris)* and dog fennel *(Anthemis cotula)* occurred in the experimental area.

RESULTS

Pre-planting Treatments

The effects of pre-planting treatments on the growth of strawberry plants and on the control of weeds are shown in Tables 1 to 3.

A comparison between the mean number of leaves on the mother plants on June 11 and the mean number of runners on June 11 in Table 1 shows that the number of runners is a more sensitive indicator of strawberry plant response than is number of leaves on mother plants. The same response was obtained the second year. Runner production was also a more sensitive indicator of herbicide effects on strawberry plants than was survival of mother plants (Table 1).

In 1952 there was no injury to strawberry plants from the following pre-planting treatments at Beltsville: SES at 3 and 6 pounds per acre, 2,4–D at 2 and 4 pounds per acre, MCP at 2 pounds per acre, CIPC at 6 pounds per acre, and DNBP at 6 pounds per acre (Table 1). The low rates of CIPC and DNBP gave 86 to 95 per cent weed control for 90 days after treatment with no injury to the strawberries. The high rates of MCP, CIPC, DNBP, and CMU were injurious to strawberries but gave excellent weed control for 90 days after treatment (Table 1). Since the low rates of CIPC and DNBP as pre-planting sprays did not injure the strawberry plants, these compounds and CMU were selected for further evaluation as pre-planting treatments.

[3]Grateful acknowledgment is given Mr. W. Lee Allen, of the W. F. Allen Company, who generously provided all facilities for the work at Salisbury and cared for the plots during the course of the work.

Table 1. Effect of pre-planting herbicide treatments on the control of weeds and growth of Tennessee Shipper strawberry plants, Beltsville, Md., 1952.

(Treatments applied April 3 and plants set April 18, 1952, 12 plants per plot)

Treatment	Rate per acre	Survival of M.P.*	Runner plants per plot			Runners rooted July 9	Leaves on M. P.†		Weed control 90 days after treatment	
			June 11	July 9	Aug. 15		June 11	July 9	Broadleaf	Grasses
	lb.	Percent	Number	Number	Number	Percent	Number	Number	Percent	Percent
SES	3	100	16	76	169	30	52	70	38	33
	6	100	14	67	149	32	50	65	60	53
2,4-D	2	91	22	74	190	24	58	58	45	30
	4	91	15	60	133	30	46	66	70	38
MCP	2	91	13	67	129	27	48	63	55	38
	4	100	10	65	169	30	48	70	62	58
CIPC	6	100	15	76	169	27	48	71	93	95
	12	100	4	48	134	31	45	78	95	98
DNBP	6	91	15	92	207	30	53	76	88	86
	12	100	11	70	170	27	50	72	94	90
CMU	1	100	8	67	142	35	55	80	95	95
	3	56	1	13	30	26	26	30	100	100
No weeding	—	100	19	60	170	30	52	64	0	0
Cultivation	—	100	18	89	211	30	58	80	55	85
Hand weeding	—	100	18	84	191	25	53	78	85	94
LSD at 5 per cent			5	24	23	—	18	21	—	—
LSD at 1 percent			7	32	31	—	24	28	—	—

*M. P. indicates mother plants or originally set plants.
†Values are for number of leaves on mother plants for entire plot.

In 1953, CIPC, DNBP, and CMU were applied as pre-planting treatments at Beltsville. Strawberry plants were not damaged by CIPC at 2 pounds per acre, by DNBP at 4 and 8 pounds per acre, or by CMU at ½ pound per acre as shown by runner counts. However, damage to strawberries did occur with CIPC at 4 and 8 pounds per acre, DNBP at 16 pounds and CMU at 1 and 2 pounds. Weed control 30 days after treating was excellent for all treatments. At 75 days after treatment, weed control with CIPC at 2 pounds was unsatisfactory, but control was good at 4 and 8 pounds per acre (Table 2). DNBP at 4 pounds was unsatisfactory 75 days after treating but at 8 and 16 pounds weed control was good to excellent. CMU at ½ pound gave very good control of broadleaf weeds, but gave unsatisfactory control of grasses. CMU at 1 and 2 pounds gave excellent weed control but strawberry plants were nearly eliminated by the 2-pound treatment (Table 2). Rainfall during April and May was very heavy (11 inches in May) in 1953 whereas precipitation in 1952 was nearly normal. Differences in rainfall and possibly the rate of CIPC evaporation may explain some of the differences in results obtained with this chemical.

In a third pre-planting experiment CIPC and DNBP were used at 2 different rates each on a fine sandy soil at Salisbury in 1953. Use of DNBP at 8 pounds per acre resulted in a 15 per cent loss of straw-

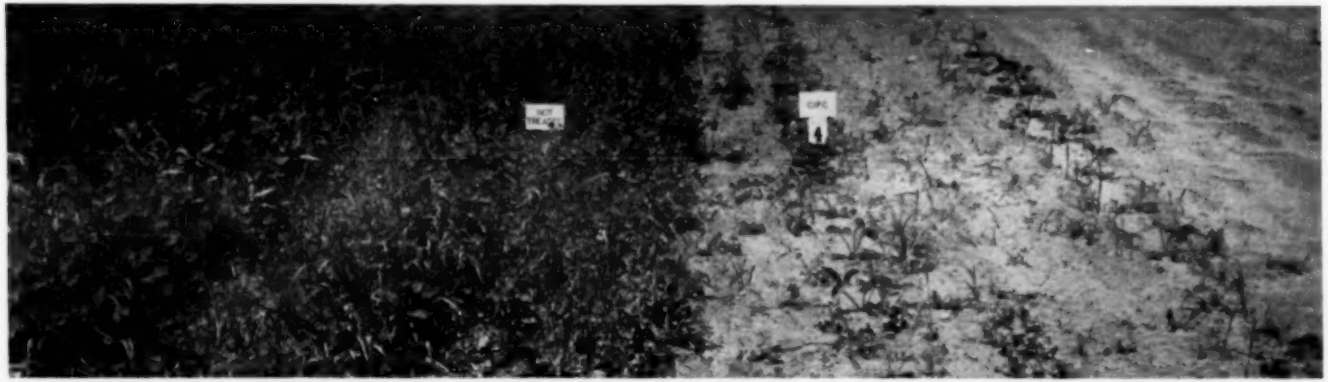

FIG. 2. Strawberry plants 65 days after preplanting treatment with herbicides, Beltsville, Md. Left to right: Untreated, CIPC 4 pounds per acre, CMU 2 pounds per acre.

FIG. 3. Strawberry plants 65 days after preplanting treatment with herbicide, Beltsville, Md. Left to right: DNBP 8 pounds per acre, cultivated, untreated.

Table 2. Effect of pre-planting herbicide treatments on the control of weeds and growth of US–4194 strawberry plants, Beltsville, Md., 1953.

(Treatments applied April 3 and plants set April 17, 24 plants per plot)

Treatment	Rate per acre	Survival of M. P.*	Runner plants	Weed control 75 days after treatment	
			June 15	Broadleaf	Grasses
	lb.	Percent	Number	Percent	Percent
CIPC	2	100	19	28	45
	4	100	5	50	63
	8	95	1	60	78
DNBP	4	100	22	55	28
	8	100	25	78	48
	16	86	5	95	83
CMU	½	96	19	80	23
	1	88	3	95	80
	2	15	0	100	95
No weeding	—	99	11	0	0
Cultivation	—	100	27	95	95
Hand weeding	—	100	25	95	95
LSD at 5 percent			13		
LSD at 1 percent			18		

*M.P. indicates the mother plants originally set.

berry plants. Plants that survived appeared normal 54 days after the pre-planting treatments (Table 3).

CIPC at 5 pounds per acre caused temporary injury to the strawberries. However, on July 9 there were no differences among the treatments in the number of runner plants for each 200 mother plants per plot. Weed control at the end of 30 days was excellent in all treatments, but, 54 days after treatment, weed control was only fair (Table 3). Rainfall during late March and April was heavy and apparently the herbicides were not retained in the light sandy soil at Salisbury as well as they were in the loam at Beltsville.

Table 3. Effect of pre-planting and post-planting herbicide treatments on the control of weeds and growth of Blakemore strawberry plants, Salisbury, Md., 1953.

(Pre-planting treatments applied March 20 followed by SES post-planting on May 16 and June 15 to plants set April 2. Four rows per plot each 300 feet long)

Treatment	Rate per acre	Survival of M.P.* May 13	Strawberry growth May 13	Runner plants per 200 M.P. on July 9	Weed control 54 days after pre-planting treatment May 13
	lb.	Percent	Rating†	Number	Percent
CIPC pre-planting	3	99	6.0	2,141	50
CIPC pre-planting	5	99	5.3	2,174	65
DNBP pre-planting	5	92	6.0	1,954	53
DNBP pre-palnting	8	85	6.3	2,151	53
SES post-planting	3	100	—	1,990	—
Cultivation (check)	–	99	6.8	1,985	35
LSD at 5 percent			0.74	N.S.	8.7
LSD at 1 percent			1.04	N.S.	12.2

*M. P. indicates mother plants originall set.
†Rating of 1 to 10 with 1 the least growth and 10 the most vigorous growth of the plants.

Post-planting Treatments for Summer Weed Control

The effects of post-planting treatments on growth of strawberry plants and on the control of weeds are shown in Tables 4 to 8.

In 1951 at Beltsville, preliminary work was begun using 2,4–D at 2 rates, CIPC at 3 rates, and SES at 3 rates as post-planting sprays. The data indicate that the only damage to strawberry plants occurred with 1.5 pounds per acre of 2,4–D on Tennessee Beauty and with 15 pounds per acre of CIPC on both varieties (Table 4). There were no significant differences in yield of Tennessee Shipper among any of the herbicide treatments, but strawberry plants in the unweeded plots were severely damaged by weed competition and the yields from these plots were less than ¼ as much as those in the cultivated plots. Yields varied greatly from plot to plot regardless of treatments because of variable soil conditions. Weed control 30 days after treating was excellent following all herbicide treatments. There was no difference in the effectiveness of the 4- and 8-pound rates of SES for weed control and little difference between the 2- and 4-pound rates. Four pounds per acre of SES was apparently adequate for very good control of weeds for 1 month (Table 4.)

Table 4. Effect of herbicide post-planting treatments on growth of Tennessee Beauty strawberry plants, on growth and yield of Tennessee Shipper and on weed control, Beltsville, Md., 1951.

(Treatments applied May 15 on plants set April 1, followed by a uniform application to all plots of 3 pounds per acre of SES on July 9, 16 plants per plot)

Treatment	Rate per acre	Survival of M.P.	Runners per variety June 25		Weed control 30 days after treating		Yield Tennessee Shipper, 1952
			Tennessee Shipper	Tennessee Beauty	Broadleaf	Grasses	
	lb.	Percent	Number	Number	Percent	Percent	Qts/A
2,4-D	0.75	98	30	33	75	90	7,010
	1.5	96	21	7	90	95	6,223
CIPC	2.5	94	33	23	75	90	6,056
	5.0	100	33	30	90	95	5,476
	15.0	96	13	12	95	95	6,513
SES	2.0	100	41	41	70	90	5,434
	4.0	100	38	44	90	95	6,845
	8.0	98	32	28	95	95	6,223
Cultivation	——	100	38	41	95	95	6,347
No weeding	——	96	42	42	0	0	1,452
LSD at 5 percent			18	25			3,327
LSD at 1 percent			24	34			

In 1952 the work at Beltsville was expanded and comparisons were made between 2 rates of SES, 2,4–D, MCP, CIPC, DNBP, and CMU (Table 5). All plots were cultivated on June 19 and given uniform treatment thereafter. Strawberry runner plants were counted on June 11, July 13, and August 15 and survival of mother plants was tabulated on June 11, 40 days after treatment.

The greatest reduction of mother plants resulted from the 4-pound DNBP treatment followed by the 1-pound CMU application. There was no damage to strawberry runner plants from SES at 3 and 6 pounds, 2,4–D at 1 and 2 pounds, and CIPC at 3 pounds per acre

(Table 5). There were differences in the per cent of runner plants rooted July 13, 75 days after treatment, but these differences were not always correlated with the amount of chemical applied.

Table 5. Effect of herbicide post-planting treatments on growth of Tennessee Shipper strawberry plants, and on weed control, Beltsville, Md., 1952.

(Treatments applied May 1 on plants set April 18, 6 plants per plot)

Treatment	Rate per acre	Survival of M.P.*	Runner plants			Runners rooted July 13	Weed control 60 days after treatment	
			June 11	July 13	Aug. 15		Broadleaf	Grasses
	lb.		Number	Number	Number	Percent	Percent	Percent
SES	3	100	9	47	95	43	54	65
	6	100	7	47	104	40	93	93
2,4-D	1	100	6	42	80	33	94	93
	2	100	5	38	79	36	85	89
MCP	1	96	1	18	64	27	86	78
	2	87	1	11	52	26	80	70
CIPC	3	96	6	27	63	32	94	94
	6	91	0	8	31	50	98	99
DNBP	2	75	1	22	65	30	94	91
	4	30	0	4	16	29	96	96
CMU	½	96	1	14	40	33	100	100
	1	41	0	0	0	0	100	100
No weeding	–	100	10	36	69	39	0	0
Cultivation	–	96	5	34	58	38	50	65
Hand weeding	–	100	7	41	117	39	90	85
LSD at 5 percent			4	15	40			
LSD at 1 percent			6	20	53			

*M. P. indicates mother plants or originally set plants.

Control of weeds 60 days after treatment was excellent with SES at 6 pounds, 2,4–D at 1 and 2 pounds, CIPC at 3 and 6 pounds, DNBP at 2 and 4 pounds, and CMU at ½ and 1 pound per acre (Table 5). SES at 6 pounds and CIPC at 3 pounds per acre were the most favorable treatments for weed control and freedom from damage to the strawberry plants in this experiment.

A second experiment was conducted in 1952 near Salisbury using different SES treatments. The results of SES on strawberry plants are presented in Tables 6 and 7. Winter weed-control treatments were superimposed on plots which had also been previously treated for the control of summer annual weeds. There was no damage to the strawberry plants from any of the SES treatments (Table 6). The plots were cultivated and hoed each time before a new application was made. No attempt was made to obtain weed control ratings during the summer months, but it was estimated that 75 to 85 per cent of the hand hoeing was eliminated by using SES every month and 60 to 70 per cent by using it every 6 weeks. The treatment applied May 1 was not as effective in controlling weeds as the treatment applied May 15. SES applied in late fall delayed emergence of chickweed but did not eliminate it. Weed control ratings made on February 10, before late-winter herbicide treatments were ap-

plied indicated no control of chickweed from any of the SES treatments (Table 7). Chickweed was the principal weed present at that time. Strawberry plants showed no injury from any of the SES treatments, even though some of the treatments were applied during the period when fruit-bud formation occurred.

Table 6. Effect of SES post-planting treatments on growth of Tennessee Beauty strawberry plants, Salisbury, Md., 1952.

(Treatments applied to plants set April 21, 4-row plots 200 feet long)

May to Sept. treatments with SES at 3 lb./A per application	Applications	Runners on 50 M.P.*		Runners rooted July 11	Runners in 20-ft. row October 8	Runners rooted October 8
		June 13	July 11			
	Total no.	Number	Number	Percent	Number	Percent
Each month	5	32	295	35	266	92
Every 6 weeks	4	34	290	35	250	91
May 15 and June 15	2	—	—	—	317	89
September 15	1	—	—	—	313	84
None (cultivation)	–	37	291	36	317	90
LSD at 5 percent		NS	NS	NS	NS	NS

*M. P. indicates mother plants or originally set plants.

In 1953 at Beltsville SES and Sesin were compared (Table 8). Sesin gave somewhat better weed control than SES and there was no damage to strawberry plants as shown by runner counts.

Foliage Treatments For Winter Weed Control

Several treatments for the control of winter weeds were compared in the same experiment in which a number of treatments were evaluated for the control of summer annual weeds (Table 7). The soil was an Elkton light clay loam and the field was heavily infested with chickweed.

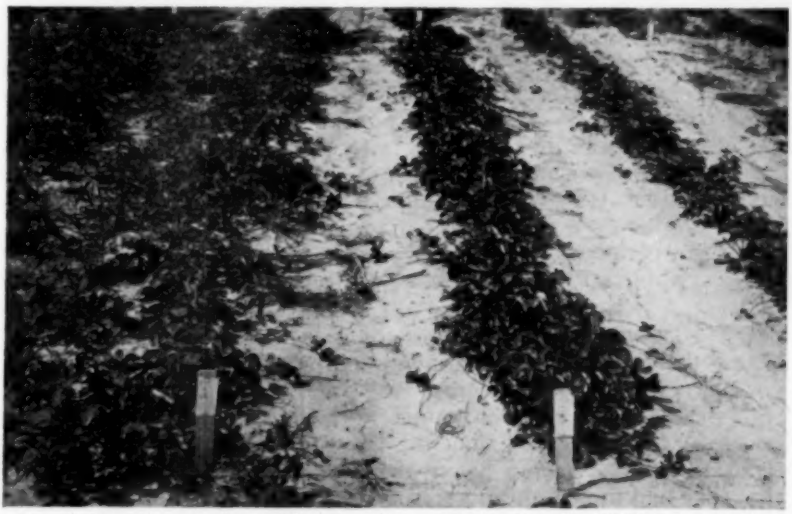

FIG. 4. Strawberry plants 35 days after post-planting herbicide treatment, Beltsville, Md. Left, untreated; right, Sesin 3 pounds per acre.

Table 7. Effect of combinations of summer, fall, and winter applications of herbicides on the control of weeds and yield of Tennessee Beauty strawberry, Salisbury, Md., 1952–53.

(Treatments applied to plants set April 21, 1953, 4-row plots 200 feet long)

Summer and fall treatments with SES at 3 lb./A per application	Applications	Fall and winter treatments*			Weed control			1953 yields per acre
		Month	Chemical	Rate p/acre	Nov. 19†	Feb. 10‡	May 7§	
	Number			lb.	Percent	Percent	Percent	Qts.
Each month from May 15 to Nov. 15	7	February	DNBP	2	73	45	80	6,655
May and June	2	February	DNBP	2	45	33	75	6,654
May and June	2	November	DNBP	1	—	50	40	6,978
May and June	2	December	DNBP	1	—	55	50	7,513
May and June	2	Nov. and Dec.	DNBP	1	—	68	60	7,090
Every 6 weeks from May 1 to November 1	5	February	DNBP	2	50	38	80	6,357
September 15	1	February	DNBP	1	50	35	70	6,170
October 15	1	February	DNBP	1	73	40	75	8,098
Oct. 15 and Nov. 15	2	February	DNBP	1	68	38	70	7,800
May and June	2	November	CIPC	3	45	90	60	5,847
Oct. 15	1	February	CIPC	3	73	38	90	7,489
Cultivation only	–	———	Hand hoeing	–	53	35	50	6,568
LSD at 5 percent								1,496
LSD at 1 percent								2,015

*Fall and winter applications were made on plots that had previously received summer or fall treatments.
†Same day that treatments were applied in November.
‡Five days prior to application of treatments in February.
§Two weeks prior to harvest.

On November 19 there was less chickweed in plots treated with SES October 15 than in those treated September 15 or in the cultivated plots (Table 7). However, by February 10 there was no difference in weed ratings between any of the SES treatments and the untreated plots.

The use of DNBP at 1 pound per acre in mid-November plus mid-December gave good control of chickweed. The split applications were more effective than 1 pound per acre applied in either mid-November or mid-December but were not as effective as a single application in February. DNBP applied in November or December were much less effective than single treatments applied in February. When DNBP at 2 pounds per acre was applied in mid-February, weed control was very good, as shown by the ratings on May 7. The 2-pound application was superior to the 1 pound rate.

CIPC at 3 pounds per acre applied in mid-November gave excellent control of chickweed, but the elimination of chickweed permitted the rapid growth of other weeds, especially winter cress and dog fennel. February applications of CIPC resulted in excellent chickweed control and were much more effective in controlling winter cress and dog fennel than the November applications. The cultivated plots had such a heavy growth of chickweed by early April that they had to be hand hoed to save the beds. However, after hand hoeing and cultivation, weed control was only fair, as shown by the May 7 rating (Table 7).

Yield records were obtained as a measure of strawberry plant response to the various treatments (Table 7). Except for one DNBP treatment applied in February, none of the yields from the different treatments were significantly different from those of the cultivated plots. The November CIPC treatment resulted in significantly lower yields than the February CIPC treatment and also some of the DNBP treatments.

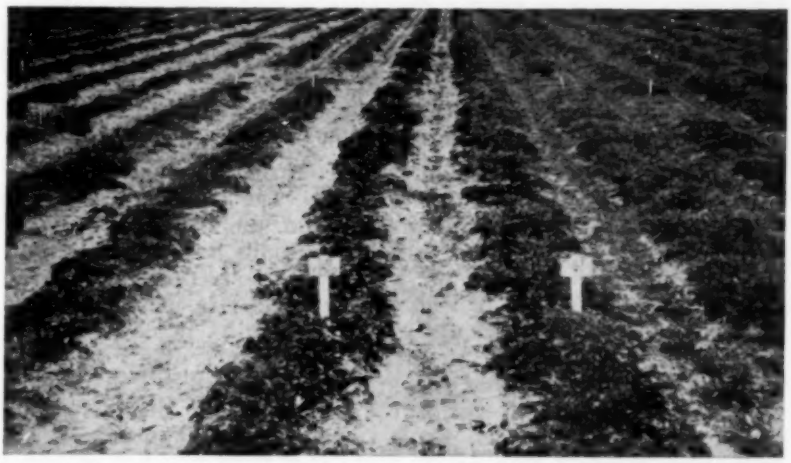

FIG. 5. Winter weed control treatment on strawberry plants, Salisbury, Md. Left, DNBP 2 pounds per acre applied in mid-February; right, untreated plot with chickweed. Photographed March 18, 1953.

FIG. 6. Winter weed control treatment on strawberry plants, Salisbury, Md. Left, CIPC 3 pounds per acre applied in November; right, DNBP 2 pounds per acre applied in February. Chickweed eliminated by CIPC but winter cress and dog fennel survived. Photographed March 18, 1953.

Table 8. Effect of herbicide post-planting treatments on growth of US–4194 strawberry plants and on weed control, Beltsville, Md., 1953.

(Treatments applied July 17 and September 3 to plants set April 17; 24-plant plots)

Treatment	Rate per acre	Weed control August 31		Runner plants October 14	Fruit yield 1954
		Broadleaf	Grasses		
	lb.	Percent	Percent	Number	Qt./A
SES	3	73	74	541	10,190
Sesin	3	91	93	665	12,050
Cultivation	–	—	—	718	11,400
LSD at 5 percent				NS	NS

DISCUSSION

These investigations involving the control of early-germinating spring weeds by pre-planting treatments, the control of summer annuals by post-planting treatments, and the control of winter annual weeds by applying herbicides in late fall or during the winter while strawberry plants were dormant were conducted on two soil types. Response of vigorous virus-free strawberry plants to different herbicide treatments was measured by determining the survival of mother plants, the number of runner plants produced by a given date, the number of runner plants rooted by a given date, the number of leaves present on the mother plants, and fruit yield. The production of runner plants appeared to be a more sensitive indication of plant response to herbicides than number of leaves on the mother plants or survival of mother plants.

The evaluation of herbicides as pre-planting treatments for weed control in strawberries indicated that 6 to 8 pounds per acre of DNBP was very satisfactory on a loam soil with very good weed control for 75 to 90 days after treating. However, on a light sandy soil, strawberry plants were damaged by an 8-pound application and control of weeds was only fair. CIPC at 4 to 6 pounds per acre gave very good control of weeds, but the strawberry plants were damaged slightly in one of the three pre-planting experiments. DNBP in this work gave more uniform results as a pre-planting herbicide than did CIPC. CMU was not sufficiently selective as a pre-planting treatment for safe use for weed control in strawberries on the soils studied. All other chemicals that were studied as pre-planting treatments did not have as long residual effect in the soil as DNBP or CIPC and were less effective in controlling weeds.

Post-planting treatments of 2,4–D at 1 and 2 pounds and SES at 3 to 6 pounds per acre were very effective treatments that did not damage the strawberry plants. SES at 3 to 6 pounds did not produce any epinastic effect whereas 2,4–D at 1 and 2 pounds produced epinastic effects but these were not accompanied by a reduction in the number of runners. Growers who have used 2,4–D hesitate to use this chemical because of the epinastic effects of the compound. Since in these studies SES gave better control of grasses than 2,4–D and did not injure strawberries when used at any stage of growth including fruit-bud formation, it would appear much safer to use

than 2,4–D. However, SES may not be effective at low soil temperatures such as exist in early spring or under very dry soil conditions as noted by Vlitos (20). The residual action of SES varied greatly depending on the amount of rainfall and soil type, and 4 to 6 weeks appeared to be the limit of its effectiveness in the soils studied.

Although only limited evaluation of Sesin was made, the material appeared promising for post-planting use. Since it had a longer residual effect than SES, it appeared worthy of further evaluation for pre-planting treatments. Other preliminary work indicated that Sesin was superior to SES in residual herbicidal properties (19).

The control of winter weeds in strawberries with CIPC and DNBP was excellent and dormant strawberry plants possessed considerable tolerance to these compounds. CIPC at 3 pounds per acre effectively controlled chickweed and did not injure strawberry plants. It is possible that lower rates of application of CIPC would be sufficient to eliminate chickweed in strawberries, depending upon the density of the chickweed, the soil type and other factors. When CIPC was applied late in the fall (November 19), chickweed was killed, but weeds tolerant to CIPC grew vigorously and became highly competitive. When CIPC was applied in mid-February, about 5 weeks elapsed before the chickweed died and other weeds did not appear in these plots until late spring. At harvest, the February CIPC-treated plots had fewer weeds than those in any other treatment.

DNBP at 1 or 2 pounds per acre gave satisfactory control of winter weeds when only small plants of chickweed were present. Large clumps of chickweed were not killed and these became serious before the fruit could be harvested. There was no damage to the strawberry plants from the DNBP treatments when they were applied while the plants were dormant. Klingman and Morrow (14) had very good results from the use of DNBP at 3 pounds per acre for control of winter weeds in North Carolina. Chickweed was not present in quantity in their experiments. Danielson and Hofmaster (5) and Rahn and Hitz (17) obtained very good control of winter weeds in strawberries with the dinitro compounds. These results seem to be in general agreement with reports from various places that winter weed control in strawberries can be very effectively accomplished by the use of DNBP when the chickweed infestation is not dense or matted. Winter weed control treatments with chemicals appeared to be less erratic than summer chemical weed control treatments.

SUMMARY

The studies reported herein may be summarized as follows:

1. Pre-planting treatments were effective for controlling weeds early in the season in new plantings of strawberries on a loam soil. Pre-planting treatments were less effective on a light sandy soil.
2. DNBP at 8 pounds per acre was the most satisfactory pre-planting treatment. Weed control was excellent for 30 days and good for 75 days after treatment with no injury to strawberries on a loam soil.

3. CIPC at 6 pounds per acre as a pre-planting treatment injured strawberry plants in one experiment, but not in two others. Weed control was excellent for 30 days and good for 75 days after treatment.
4. Seven post-planting treatments with SES at 3 pounds per acre at monthly intervals did not damage strawberry plants and gave very good control of weeds for 4 weeks after each application.
5. SES applied at different times during fruit-bud formation was not injurious to strawberry plants.
6. Sesin appeared promising for post-planting use and may be of value for pre-planting treatments.
7. CIPC at 3 pounds per acre applied either in mid-November or mid-February to dormant strawberry plants gave excellent control of chickweed without damage to strawberries.
8. A single application of DNBP at 1 or 2 pounds per acre in mid-February gave better control of weeds at harvest time than a split application of 1 pound in mid-November and 1 pound in mid-December. There was no damage to the strawberry plants as indicated by yield of fruit from any DNBP treatment used while the strawberry plants were dormant.
9. The number of runner plants produced by a specific date was found to be a sensitive indicator of the effect of herbicides on strawberries and an adequate response index to use for the evaluation of new chemicals for weed control in strawberries.
10. In these investigations, a combination of chemical applications consisting of a pre-planting treatment of CIPC or DNBP, followed by post-planting treatments of SES at 30 day intervals or as needed, and CIPC or DNBP applied for the control of chickweed and other winter annual weeds when strawberries were dormant, resulted in excellent weed control, without injury to the strawberry plants. This combination of treatments eliminated most of the need for hand hoeing for the control of weeds.

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News and Weeds Affairs

Laramie, Wyoming Is New Regional Headquarters of ARS Weed Investigations

The western regional headquarters of the Weed Investigations Section, Agricultural Research Service, U. S. Department of Agriculture, has been moved to the University of Wyoming at Laramie from the Utah Agricultural Experiment Station at Logan, where the regional headquarters has been located since June 1948. Mr. F. L. Timmons, Regional Coordinator, moved to Laramie September 1, 1954. His assistant, Mr. W. O. Lee will be transferred from Logan to Laramie about November 1 after field experiments in Utah have been completed.

The halogeton control investigations, begun in Utah in October 1952, will be continued by Dr. L. L. Jensen and Mr. E. H. Cronin of the Weed Investigations Section of ARS cooperating with the Utah Agricultural Experiment Station at Logan.

Stationing Messrs. Timmons and Lee at the Wyoming Agricultural Experiment Station provides wider distribution of the Section's cooperating research projects in the region. Cooperative projects are now located in nine of the eleven western states.

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for October, November, and December 1953

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Prepared By

Division of Weed Investigations, Bureau of Plant Industry, Soils, and Agricultural Engineering, Agricultural Research Administration, United States Department of Agriculture

This bibliography of current literature on weeds and their control is issued as a service to those engaged in weed research in the United States and other countries. In issuing this bibliography the Section of Weed Investigations does not assume responsibility for the subject matter cited.

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